A STATE-OF-THE-ART DESIGN TECHNIQUE IN LANDFILL ENGINEERING : A CASE STUDY

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ABSTRACT

Disposal of solid wastes, the final functional element of the solid waste management system, is a major problem throughout the industrialized world. Sanitary landfilling is today widely recognized as the most common and economic method and viable solution for the disposal of municipal and industrial solid wastes. Despite the implementation of waste reduction, recycling and transformation technologies, disposal in landfills still remains an important component of integrated solid waste management strategy.

The purpose of this study was to present the design steps of sanitary landfills through Sinop (Meşedağı) sanitary landfill project. The study indicates that planning and design of modern landfills, involves the application of a variety of scientific, economic and engineering principles. The main criteria in design studies were the Turkish Environmental Regulations.

The other main feature of the study was the evaluation of the different models and approaches employed in the design of modern landfills. In this manner, it is intended to gather appropriate data by comparing the results. The major topics covered in this study include description of the landfill site, estimation of population and solid waste generation, definition of waste properties, slope and berm stability analysis, design of sub-base liners and final cap, estimation of leachate generation and design of leachate collection system, design of surface water drainage system, estimation of gas generation and design of gas venting system, design of leachate treatment plant, and closure of landfill and longterm monitoring.

ÖZET

Katı atık yönetim sisteminin fonksiyonel son öğesi olan katı atıkların uzaklaştırılması, gelişmiş ülkelerde başlıca bir sorun olarak ortaya çıkmaktadır. Günümüzde, düzenli depolama, evsel ve endüstriyel katı atıkların uzaklaştırılmasında en yaygın, en ekonomik ve en uygun yöntem olarak bilinmektedir. Üretilen atık miktarının azaltılması, geri dönüşüm ve transformasyon teknolojilerinin de uygulamaya geçmesi, depolamayı katı atık yönetim stratejisinin önemli bir öğesi haline getirmiştir.

Bu çalışmanın amacı, düzenli depolama tesislerinin tasarımında takip edilecek tasarım adımlarını, Sinop (Meşedağı) düzenli depolama tesisi projesi ile sunmaktır. Çalışma göstermektedir ki, bir depolama tesisinin planlanması ve tasarımı farklı bilimsel, ekonomik ve mühendislik ilkelerinin uygulanmasını gerektirmektedir. Tasarımda göz önünde bulundurulan en önemli kriter Türk Çevre Mevzuatı olmuştur.

Çalışmanın önemli diğer bir özelliği ise sonuçlara ulaşmak için farklı model veya yaklaşımların kullanılmış olmasıdır. Böylece, elde edilen sonuçların birbiriyle karşılaştırılması yapılarak en uygun verilerin elde edilmesi amaçlanmıştır. Çalışma ana başlıklarıyla depolama alanının tanıtımı, nüfus ve katı atık üretim tahminleri, katı atık özelliklerinin tanımı, depolama alanı alt ve üst tabakaların tasarımı, eğim ve bend stabilite analizleri, sızıntı suyu oluşumu tahminleri ile sızıntı suyu toplama sisteminin tasarımı, yüzey suyu drenaj sisteminin tasarımı, gaz oluşum tahminleri ile gaz uzaklaştırma sisteminin tasarımı, sızıntı suyu arıtma tesisinin tasarımı ve son olarak da depolama alanının kapatılması ile uzun dönem izleme çalışmalarını kapsamaktadır.

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BOD	Biological oxygen demand
COD	Chemical oxygen demand
C / N / P	Carbon / Nitrogen / Phosphorus
cap.	Capita
GAC	Granular activated carbon
Ha	Hectar
HELP	Hydrologic evaluation of landfill performance
kg	Kilogramme
km	Kilometer
l	Liter
m	Meter
m^3	Cubic meter
mg	Miligram
min	Minute
MSW	Municipal solid waste
MSWLF	Municipal solid waste landfill
SBR	Sequenching batch reactor
sec	Second
TCOD	Total chemical oxygen demand
U.S.	United States
y	Year

1. INTRODUCTION

Problems associated with solid wastes have become a world-wide concern as a result of population increases, industrialization and urbanization.

The term solid waste is commonly used to describe residential solid or semi-solid materials, in addition to those from the industrial, agricultural, and commercial sectors that are discarded as useless or unwanted. The combination of residential and commercial waste is usually referred to as municipal solid waste. The term solid waste includes the heterogeneous mass of throwaways from the urban community as well as the more homogeneous accumulation of agricultural, industrial, and mineral wastes. Solid wastes are heterogeneous in composition and characteristics reflecting the economic status, lifestyle, consumer orientation, cultural and technological advancement of the community. Accordingly, quantities and composition of municipal solid wastes exhibit wide variations among sources as well as time and seasons emphasizing that typical solid waste characteristics can be highly variable depending on site specificity (Al-Yousfi, 1992).

1.1. Waste Generation

The quantities of solid wastes produced by the world developed nations are large and increasing along with a growing affluence and improved standard of living. The amount of solid waste production in Turkey is 0.61 kg/cap.-day. This value is 1.5-2 kg/cap.-day in Europe and 3 kg/cap.-day in the U.S (Demir et al., 1999). In addition, approximately one-half of the 6,000 U.S. landfills are expected to be filled by the mid 1990s. Refuse quantities, in conjuction with the fact that landfills are reaching capacity, indicate very severe impending problems. To make problems worse; some existing landfills and incinerators will not be able to meet stringent federal, state and local environmental regulation and will be forced to close (McBean et al., 1995).

1.2. Development of Solid Waste Management

The relationship between public health and the improper storage, collection and disposal of solid wastes is quite clear. The U.S. Public Health Service (USPHS) has published the results of a study tracing the relationship of 22 human diseases to improper solid waste management (Tchobanoglous et al., 1993).

At that point, it is seen that clean and healthy living conditions in cities, towns and villages can not be achieved without a proper solid waste management. Solid waste management can be defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing, and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations, and that is also responsive to public attitudes. In its scope, solid waste management includes all administrative, financial, legal, planning, and engineering functions involved in solutions to all problems of solid wastes (Tchobanoglous et al., 1993).

Currently, Turkey has nearly all the applicable mainframe environmental regulations in effect (Zanbak, 1998). The activities about solid waste management are executed according to these regulations with the leadership of municipalities. At the national level, the Ministry of Environment has been established in 1991 for coordinating all governmental activity on the protection of the environment (Çoban, 1998). The Ministry of Environment have enacted the following regulations on solid waste management:

1) The Solid Waste Control Regulation (14th of March 1991)
2) The Medical Wastes Control Regulation (20th of March 1993)
3) The Hazardous Waste Control Regulation (27th of August 1995)

Additionally, a new revision has been published in 2000, which including new modifications to the previous Solid Waste Control Regulation stated above.

1.3. Sanitary Landfilling

The final functional element of the integrated solid waste management system is the disposal of wastes. A modern sanitary landfilling is an engineered facility used for disposing of solid wastes on land or within the earth's mantle without creating nuisances or hazards to public health or safety. Sanitary landfilling is an acceptable and recommended method for ultimately disposing of solid wastes (Weiss, 1974).

Reviewing the solid waste disposal applications Turkey reveals that open dumping is the most common disposal method. There are many drawbacks of open dumping for the environment and public health, like odor generation, breeding of flies, pollution of the surface and groundwaters, fires and explosion risks. The accident in Ümraniye-Hekimbaşı Open Dumping Site on April 28, 1993 is one of the most remarkable and dramatical example of the inproper landfilling of the solid wastes.

In 1992, CH_2M Hill carried out a study in order to examine a proper disposal method for Istanbul. According to the results, the unit costs for the disposal methods are as follows (Demir et al., 1999):

- Sanitary Landfilling : 8.5 U.S. $ / ton solid waste
- Composting : 10.5 U.S. $ / ton solid waste
- Incineration : 80.97 U.S. $ / ton solid waste

The results indicate that sanitary landfilling can be an acceptable method for the disposal of solid wastes for Turkey. The traditional definition of sanitary landfill has been set forth by the American Society of Civil Engineers as: "disposing of refuse on land without creating nuisances to public health or safety by utilizing the principles of engineering to confine refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of every day's operation, or at more frequent intervals if necessary" (Sanitary Landfill, 1974).

1.4. Objectives and Scope

The objective of this study is to present proper design elements of a modern sanitary landfill through a case study. A State-of-the-Art study includes a case study involving a MSW sanitary landfill design project in Sinop (Meşedağı) for years 2000 – 2030.

In Section 2. the description of the project area is given. The location. transportation facilities. population characteristics. economic conditions. climate. geology and hydrogeology of Sinop are explained in detail. Section 3 presents the population estimation studies. Depending on the evaluation of the results of the population projections. Bank of Provinces method is preferred to be used in the study. Section 4 presents the estimations on solid waste quantity. The total amount of solid wastes that will be disposed in Sinop (Meşedağı) Sanitary Landfill include MSW from residences. MSW from industries. MSW from military services and dewatered sludge from primary wastewater treatment plant. In Section 5. the sources. types and properties of solid wastes in Sinop are reviewed. The solid wastes resources are from residences. industries. military facilities and the treatment plant. and include food wastes. papers. plastics. textiles. woods. metals. dirts. ashes and sludge. Section 6 presents the information about the landfill site with stability analysis of slopes and berms for each lot. In Section 7. the liner materials are reviewed and the details of the design of the subbase liner system and the final cap is given. Section 8 presents the evaluation of leachate generation and design of leachate collection system. The numerical models selected to evaluate the potential leachate quantity and composition from this landfill are the HELP (Hydrologic Evaluation of Landfill Performance) and Water Balance Model, respectively. Section 9 presents the design of surface water ditches and culverts which are the main structures in surface water drainage system. The trapezoid shaped stormwater ditch and circular culverts are designed to drain water. The trapezoid is the most common shape for channels with unlined earth banks. In Section 10. the amount of gas generation is evaluated, then gas venting system design is given. Two different methods are used to evaluate the potential gas generation; a) Evaluation according to the chemical formula. and b) LandGEM (Landfill Gas Emissions) Model. An active venting system consisting of a series of horizontal and vertical extraction wells connected by a header pipe releasing the gas to the atmosphere is designed. The main reasons of choosing this system are the waste characteristics. location of the landfill area.

the regulatory statements and the economical conditions. Section 11 presents the design of the leachate treatment plant. The main criteria was that effluent from the designed leachate treatment plant will be discharged to Black Sea via creek and the effluent concentrations must meet the standards stated in the Water Pollution and Control Regulation, 1988. The proposed treatment plant consists of an equalization tank, ammonia stripping unit in combination with pH adjustment, anaerobic upflow hybrid bed reactor, pre-ozonation, sequenching batch reactor (SBR); post-ozonation, sand filter and granular activated carbon (GAC) filter units. In Section 12, longterm monitoring principals after the closure of landfill are presented. Finally, Section 13 presents the overall summary and the conclusions of this study.

2. DESCRIPTION OF THE PROJECT REGION - SİNOP

2.1. Location

Sinop is located in Middle Black Sea Region, at the northest point of Turkey on the neck of a peninsula. The city is beautifully equipped both by nature and human foresight. The neighbourhood cities are Kastamonu at the west, Çorum at the south and Samsun at the east. The location of Sinop can be seen on a map of Turkey given in Figure 2.1.

Figure 2.1. The location of Sinop in Turkey

Inland, the peninsula is isolated from the rest of Asian Turkey by the northern chain of mountains called the North Anatolian Mountains. The highest peak near the peninsula is Yaralıgöz which has an elevation of 1,985 m. The peninsula is divided by the Karasu River, and about 96 km to the east, flows the Kızıl River, better known as the Halys River in ancient times (T.R. Sinop Governership, 2001).

Total area occupied by Sinop is about 5,862 km^2. The main mountains in the region are Zindan (1,730 m.), Çangal (1,605 m.), Elekdağ (1,440 m.), Dranaz (1,345 m.), Soğuksu

(1,200 m.) and Kösedağı (900 m.); the major rivers are Gökırmak, Karasu, Ayancık and the major lakes are Sarıkum, Aksaz, Sülükoğlu, Karagöl (T.R. Sinop Governership, 2001).

2.2. Transportation

Transportation is provided by highways, seaways and airways. Sinop (centrum) is connected to neighbour cities by three national highways. The distance between Sinop-Samsun and Sinop–Ankara is 168 km and 434 km, respectively (T.R. Sinop Governership, 2001).

Transportation by seaway is also important in Sinop. There is a seaport in the city that the capacity will be improved in the near future (T.R. Sinop Governership. 2001).

There is also an airport in Sinop on which transportation is provided by the Turkish Airlines scheduled flights from Sinop to other cities of Turkey via Samsun and Ankara (T.R. Sinop Governership. 2001).

2.3. Population

According to the data of State Institute for Statistics (DIE), the total population of Sinop in 1990 is 265,153. The number of the population in city centrum is 86,314 and the number in villages is 178,839. It is seen that 67.4% of the population is in the villages and 32.6% is in the city centrum. According to 1997 counts, total population is 214,925. 40.7% of it is in the city centrum and 59.3% is in the villages (State Institute for Statistics, 2000).

In the region, there is a population increase in some periods because of the military facilities located in the city. There is also a tourism activity especially in summer season.

2.4. Economy

Sinop is a developing city. It is in the classification of first priority developing cities. The most important activities related to economy in Sinop can be listed as agriculture, industry and tourism (T.R. Sinop Governership, 2001).

2.4.1. Agriculture

The agricultural areas in Sinop are limited because of the geographical characteristics of the city. In the scope of the agricultural activities, wheat, barley and rice are the products that have economical importance. The fruit products in Sinop are pear, apple, medlar, plum, cherry, peach, mulberry and fig (T.R. Sinop Governership, 2001).

2.4.2. Industry

The industry is not very developed in the city and the number of the industrial facilities belonging to the state are low in number. However, in recent years there is an increase in the number of the facilities stated by the personal attempts (T.R. Sinop Governership, 2001).

2.5. Climate

Both East and West Black Sea climate characteristics are effective in Sinop. The precipitation occurs at high levels especially at the coast line of the city. The temperature differences between the seasons are not very high in the city (T.R. Sinop Governership, 2001).

To determine the climate of the project region briefly, observation data for many years were taken from State Institute for Statistics. In the scope of this data, precipitation, temperature, evaporation, wind direction and velocity and relative moisture values are included and given in Table 2.1.

According to these data, the highest temperatures are observed in July-August period (> 22°C) and the lowest temperatures are in observed in January-March period (<8 C) (State Institute for Statistics, 2000).

Table 2.1. Meteorological data of Sinop (State Institute for Statistics, 2000)

Months	Average Precipitation (mm)	Average Temperature (°C)	Evaporation (mm)	Dominant Wind Direction	Frequency (number/ year)	Wind Speed (m/s)	Average Relative Moisture (%)
January	73.8	6.9	35.0	NW	452	7.7	73
February	50.5	6.6	36.3	NW	448	8.1	74
March	46.7	7.1	34.6	NW	473	7.7	77
April	39.2	10.3	40.1	NW	464	6.4	79
May	35.3	14.6	41.3	SE	536	4.6	81
June	34.2	19.4	56.8	NW	517	5.1	78
July	31.1	22.4	67.9	NW	633	5.7	77
August	40.4	22.6	67.2	WNW	704	4.8	77
September	63.2	19.6	54.2	WNW	430	4.9	76
October	80.7	15.9	47.4	NW	282	6.8	76
November	88.7	12.6	43.7	WNW	355	5.9	75
December	86.2	9.3	46.7	NW	339	7.1	73
Annual	**670.0**	**13.9**	**571.2**	**NW**	**5211**	**6.5**	**76**

In addition, the precipitation frequency curves for Sinop are shown in Figure 2.2 and the meteorological data calculated according to precipitation frequency curves is given in Table 2.2.

2.6. Geology

In the region, methamorphite, gravel stone, limestone, sandy limestone, tuff and bazalt are the main geological pattern (T.R. Sinop Governership, 2001).

When sismogrophical characteristics are determined, Sinop is at the north of the North Anataolian Fault Line and far from the effect of this line. According to the earthquake map given in Figure 2.3, Sinop is on the fourth degree earthquake region (T.R. Sinop Governership, 2001).

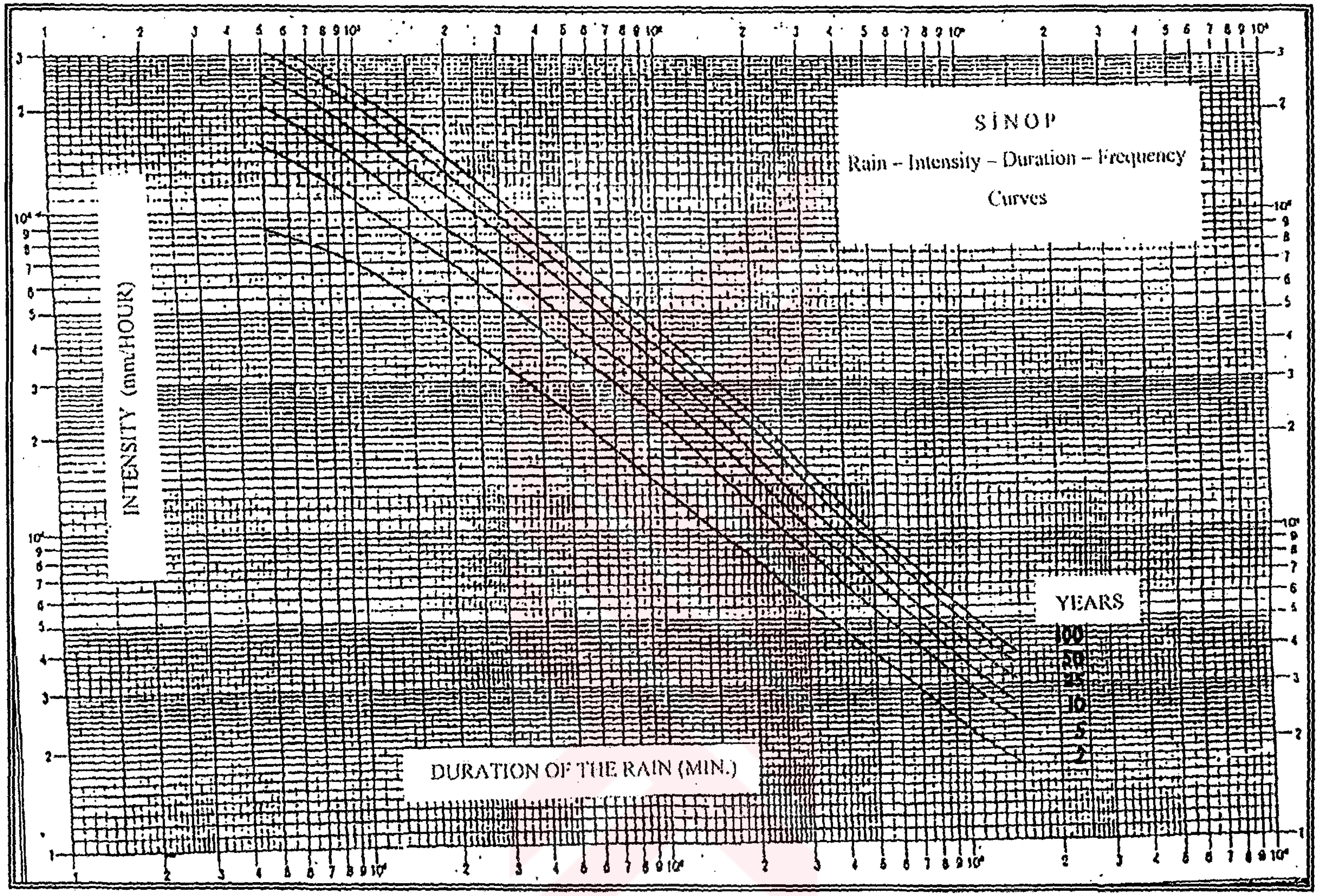
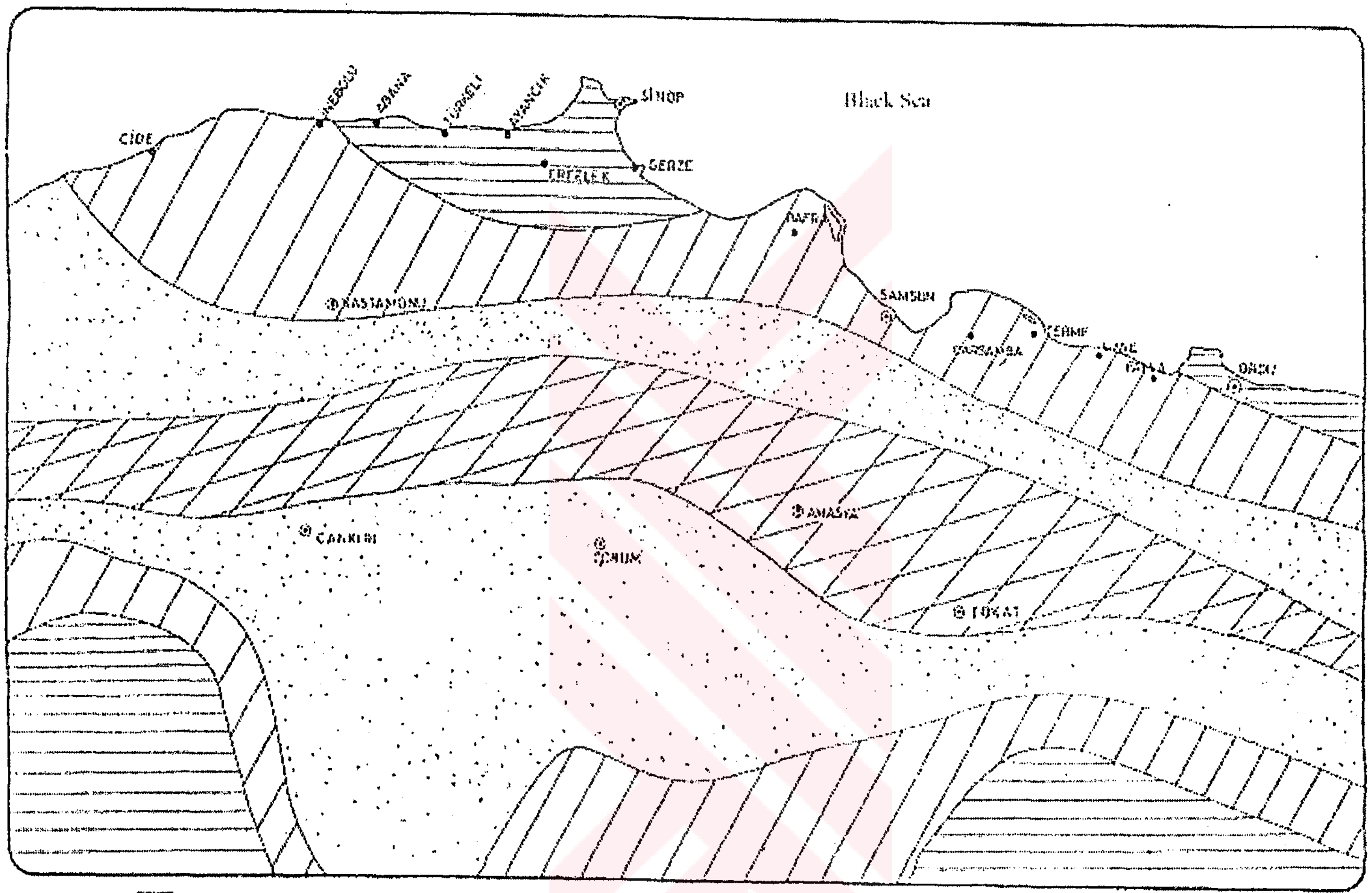


Figure 2.2. Rain – Intensity – Duration – Frequency curves prepared with the data observed in Sinop meteorological station (T.R. Sinop Governorship, 2001)

Table 2.2. The data calculated according to the observations in Sinop meteorological station

(l/sec/ha) = a* x T (min) b						
T (min.)	**100 year**	**50 year**	**25 year**	**10 year**	**5 year**	***2 year***
15	446	406	349	275	217	*134*
16	423	386	332	262	207	*128*
17	403	367	316	250	198	*123*
18	385	351	302	239	189	*118*
19	369	336	289	229	182	*113*
20	354	323	278	220	175	*109*
21	341	310	267	212	168	*106*
22	328	299	257	204	163	*102*
23	317	288	248	197	157	*99*
24	306	279	240	191	152	*96*
25	296	270	233	185	148	*93*
26	287	261	225	179	143	*91*
27	279	254	219	174	139	*88*
28	271	246	212	169	135	*86*
29	263	239	207	164	132	*84*
30	256	233	201	160	129	*82*
31	250	227	196	156	125	*80*
32	243	221	191	152	122	*78*
33	238	216	186	149	120	*76*
34	232	211	182	145	117	*75*
35	227	206	178	142	114	*73*
36	222	201	174	139	112	*72*
37	217	197	170	136	110	*70*
38	212	193	167	133	108	*69*
39	208	189	163	130	105	*68*
40	204	185	160	128	103	*66*
41	200	181	157	125	102	*65*
42	196	178	154	123	100	*64*
43	192	175	151	121	98	*63*
44	189	171	148	119	96	*62*
45	185	168	146	117	95	*61*
a*	3873,193	3559,600	3026,078	2279,484	1684,982	*943,375*
b	-0.7984	-0,8015	-0,7972	-0,7808	-0,7565	*-0,7194*



First degree earthquake region
Second degree earthquake region
Third degree earthquake region
Fourth degree earthquake region

Figure 2.3. Earthquake map of the project region (T.R. Sinop Governorship, 2001)

2.7. Hydrogeology

General geological properties show that impermeable structure exists in the project area. When the groundwater potential in the area is determined it is observed that there is not any significant groundwater potential (T.R. Sinop Governorship, 2001).

3. POPULATION ESTIMATION

One of the most important parameter for the calculation of the solid waste quantity is the population data. For the population projections. existing data records were used. In Table 3.1 and Figure 3.1, past census population records of the project region for the years 1940 – 1997 are given. By using different population projection methods. the best method that fits the real data was chosen. The tables and graphs showing the real data and corresponding projected populations according to Geometric. Arithmetic. Linear Regression and Bank of Provinces Methods are given in the following sections.

Table 3.1. Population data for the project region (State Institute for Statistics. 2000)

Years	Sinop (Centrum)	Erfelek	Gerze	Total
1940	4.838	-	3.412	8.250
1945	4,995	-	4.272	9.267
1950	5,780	-	4.320	10.100
1955	7,307	-	3,925	11.232
1960	10,214	1.890	4.680	16.784
1965	13,354	2,244	5.387	20,985
1970	15,096	2.554	6.823	24.473
1975	16,098	4,634	7,313	28,045
1980	18,328	3,066	6.327	27,721
1985	23,148	3,672	7,370	34,190
1990	25,537	4,262	8,609	38,408
1997	28,574	4,072	8,976	41.622

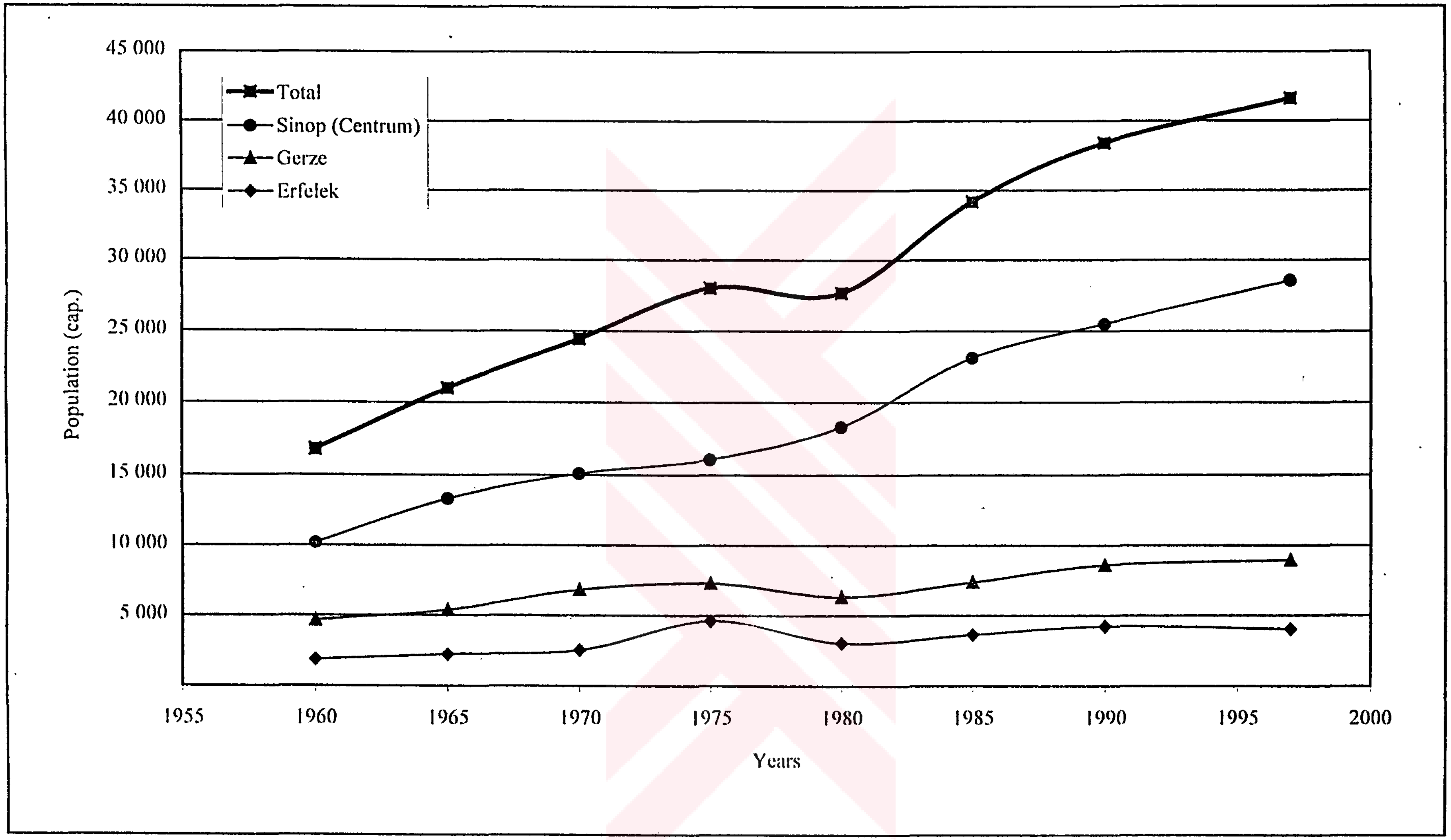


Figure 3.1. Population data of the project region

3.1. Geometric Increase Method

The formulas used in the geometric increase method are given below :

$$p_g = \ln (N_s / N_i) / a \qquad (3.1)$$

p_g : Geometric population increase coefficient

N_s : Last population data (capita) for the calculation period

N_i : Initial population data (capita) for the calculation period

a : The time between the two population census (year)

p_g^* which is the average of the p_g values is calculated as given below :

$$p_g^* = (1/k) \cdot \sum_{i=1}^{k} p_g^{i} \qquad (3.2)$$

k : number of p_g values.

and by using the formula below population estimations are done :

$$N_g = N_s \cdot e^{(pg^* \cdot n)} \qquad (3.3)$$

N_g : Future population estimation according to the geometric increase (capita)

N_s : The last census result that is taken as a basis(capita)

pg^* : Average geometric population increase coefficient

n : The time between basic year and the calculated year (year)

The population calculations and the results according to the geometric increase method are given in Table 3.2a. and 3.2b.

Table 3.2a. Geometric increase coefficients

Years	Centrum	Erfelek	Gerze
1960 – 1965	= ln(13.354/10.214)/(1965-1960) = 0.054	= ln(22.44/1.890)/(1965-1960) = 0.034	= ln(5.387/4.680)/(1965-1960) = 0.028
1965 – 1970	= ln(15.096/13.354)/(1970-1965) = 0.025	= ln(2.554/2.244)/(1970-1965) = 0.026	= ln(6.823/5.387)/(1970-1965) = 0.047
1970 – 1975	= ln(16.098/15.096)/(1975-1970) = 0.013	= ln(4.634/2.554)/(1975-1970) = 0.119	= ln(7.313/6.823)/(1975-1970) = 0.014
1975 – 1980	= ln(18.328/16.098)/(1980-1975) = 0.026	= ln(3.066/4.634)/(1980-1975) = -0.083	= ln(6.327/7.313)/(1980-1975) = -0.029
1980 – 1985	= ln(23.148/18.328)/(1985-1980) = 0.047	= ln(3.672/3.066)/(1985-1980) = 0.036	= ln(7.370/6.327)/(1985-1980) = 0.031
1985 – 1990	= ln(25.537/23.184)/(1990-1985) = 0.019	= ln(4.262/3.672)/(1990-1985) = 0.03	= ln(8.609/7.370)/(1990-1985) = 0.031
1990 – 1997	= ln(28.574/25.537)/(1997-1990) = 0.016	= ln(4.072/4.262)/(1997-1990) = -0.007	= ln(8.976/8.609)/(1997-1990) = 0.006
Average (p_g*)	**0.029**	**0.022**	**0.018**

Table 3.2b. Population projections according to the geometric increase

Years	Centrum	Erfelek	Gerze	Total
2000	= 28.574x$e^{[0.029x(2000-1997)]}$ = 31.171	= 4.072x$e^{[0.022x(2000-1997)]}$ = 4.350	= 8.976x$e^{[0.018x(2000-1997)]}$ = 9.474	44.995
2005	= 28.574x$e^{[0.029x(2005-1997)]}$ = 36.035	= 4.072x$e^{[0.022x(2005-1997)]}$ = 4.856	= 8.976x$e^{[0.018x(2005-1997)]}$ = 10.366	51.257
2010	= 28.574x$e^{[0.029x(2010-1997)]}$ = 41.658	= 4.072x$e^{[0.022x(2010-1997)]}$ = 5.420	= 8.976x$e^{[0.018x(2010-1997)]}$ = 11.343	58.421
2015	= 28.574x$e^{[0.029x(2015-1997)]}$ = 48.158	= 4.072x$e^{[0.022x(2015-1997)]}$ = 6.050	= 8.976x$e^{[0.018x(2015-1997)]}$ = 12.411	66.619
2020	= 28.574x$e^{[0.029x(2020-1997)]}$ = 55.673	= 4.072x$e^{[0.022x(2020-1997)]}$ = 6.754	= 8.976x$e^{[0.018x(2020-1997)]}$ = 13.579	76.006
2025	= 28.574x$e^{[0.029x(2025-1997)]}$ = 64.360	= 4.072x$e^{[0.022x(2025-1997)]}$ = 7.539	= 8.976x$e^{[0.018x(2025-1997)]}$ = 14.858	86.757
2030	= 28.574x$e^{[0.029x(2030-1997)]}$ = 74.403	= 4.072x$e^{[0.022x(2030-1997)]}$ = 8.416	= 8.976x$e^{[0.018x(2030-1997)]}$ = 16.258	99.077

The figure of the geometric increase for the three provinces is given in Figure 3.2. According to this scenario, the final population is estimated to be about 99,000 in the year 2030.

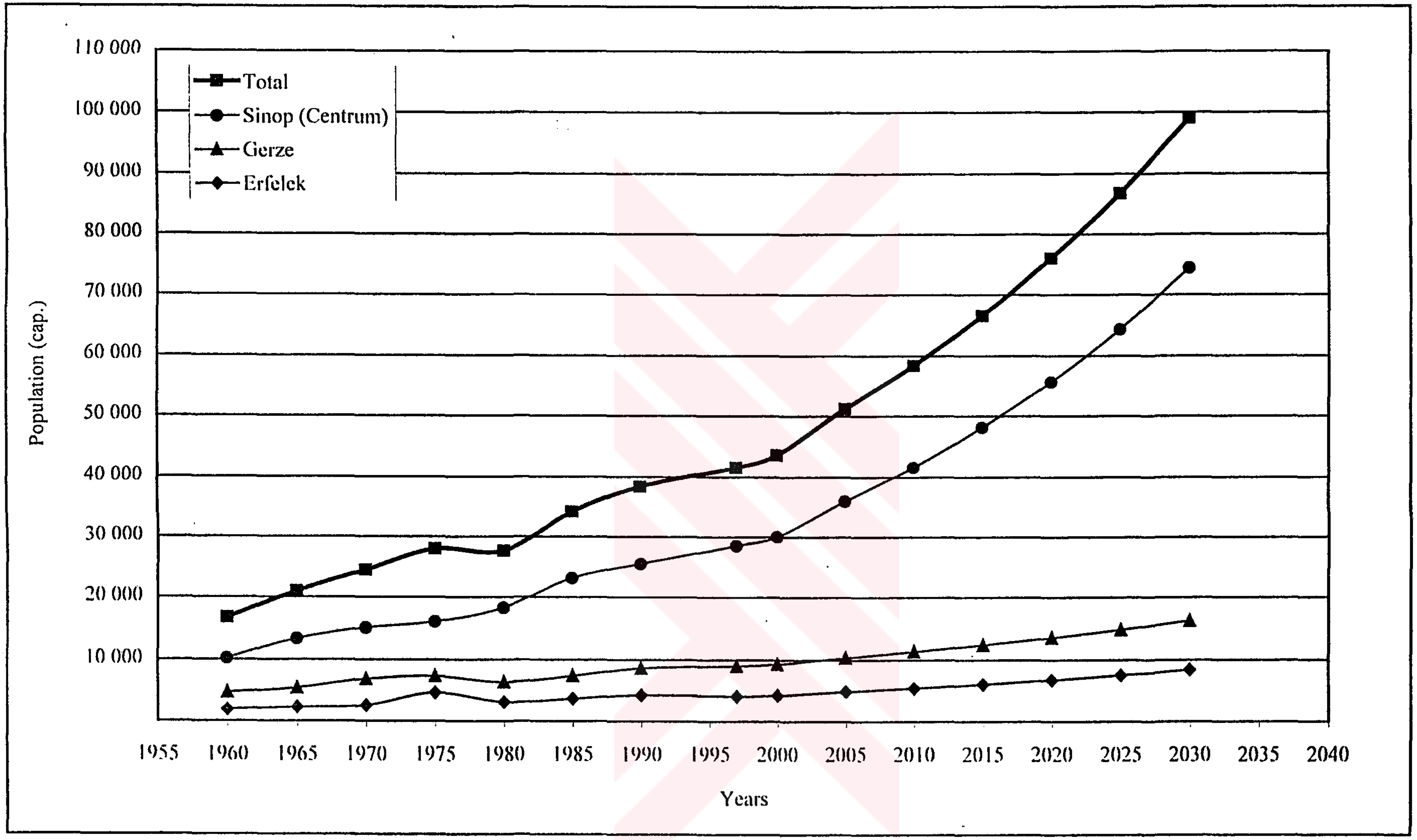


Figure 3.2. The future population projection according to geometric increase

3.2. Arithmetic Increase Method

The formulas used in the aritmetic increase method are given below :

$$p_a = (N_s - N_i) / a \tag{3.4}$$

p_a : Arithmetic population increase coefficient

N_s : Last population data (capita) for the calculation period

N_i : Initial population data (capita) for the calculation period

a : The time between the two population census (year)

p_a^* which is the average of the p_a values is calculated as given below :

$$p_a^* = (1/k) \times \sum_{i=1}^{k} p_a^i \tag{3.5}$$

k : Number of p_a values,

and by using the formula below population estimations are done :

$$N_a = N_s + (p_a^* \times n) \tag{3.6}$$

N_a : Future population according to the aritmetic increase (capita)

N_s : The last population census result that is taken as a basis (capita)

p_a^* : Average arithmetic population increase coefficient

n : The time between the basic year and the calculated year (year)

The population calculations and the results according to the geometric inrease method are given in Table 3.3a. and 3.3b.

Table 3.3a. Arithmetic increase coefficients

Years	Centrum	Erfelek	Gerze
1960 – 1965	= (13.354-10.214)/(1965-1960) = 628	= (2.244-1.890)/(1965-1960) = 71	= (5.387-4.680)/(1965-1960) = 141
1965 – 1970	= (15.096-13.354)/(1970-1965) = 348	= (2.554-2.244)/(1970-1965) = 62	= (6.823-5.387)/(1970-1965) = 287
1970 – 1975	= (16.098-15.096)/(1975-1970) = 200	= (4.634-2.554)/(1975-1970) = 416	= (7.313-6.823)/(1975-1970) = 98
1975 – 1980	= (18.328-16.098)/(1980-1975) = 446	= (3.066-4.634)/(1980-1975) = -314	= (6.327-7.313)/(1980-1975) = -197
1980 – 1985	= (23.148-18.328)/(1985-1980) = 964	= (3.672-3.066)/(1985-1980) = 121	= (7.370-6.327)/(1985-1980) = 209
1985 – 1990	= (25.537-23.148)/(1990-1985) = 478	= (4.262-3.672)/(1990-1985) = 118	= (8.609-7.370)/(1990-1985) = 248
1990 – 1997	= (28.574-25.537)/(1997-1990) = 434	= (4.072-4.262)/(1997-1990) = -27	= (8.976-8.609)/(1997-1990) = 52
Ortalama (p_a^*)	**500**	**64**	**120**

Table 3.3b. Population projections according to the arithmetic increase

Years	Centrum	Erfelek	Gerze	Total
2000	= 28.574+[500x(2000-1997)] = 30,074	= 4.072+[64x(2000-1997)] = 4,264	= 8.976+[120x(2000-1997)] = 9.336	43.674
2005	= 28,574+[500x(2005-1997)] = 32.574	= 4.072+[64x(2005-1997)] = 4.584	= 8.976+[120x(2005-1997)] = 9.936	47.094
2010	= 28.574+[500x(2010-1997)] = 35.074	= 4.072+[64x(2010-1997)] = 4.904	= 8.976+[120x(2010-1997)] = 10.536	50.514
2015	= 28.574+[500x(2015-1997)] = 37,574	= 4.072+[64x(2015-1997)] = 5,224	= 8.976+[120x(2015-1997)] = 11,136	53,934
2020	= 28.574+[500x(2020-1997)] = 40,074	= 4,072+[64x(2020-1997)] = 5.544	= 8.976+[120x(2020-1997)] = 11.736	57,354
2025	= 28.574+[500x(2025-1997)] = 42.574	= 4.072+[64x(2025-1997)] = 5.864	= 8.976+[120x(2025-1997)] = 12,336	60.774
2030	= 28.574+[500x(2030-1997)] = 45.074	= 4,072+[64x(2030-1997)] = 6.184	= 8,976+[120x(2030-1997)] = 12.936	64,194

In Figure 3.3, the populations calculated according to arithmetic increase is given for each province. It is seen that the population increase continue and will finally reach to 66,000.

3.3. Linear Regression Method

The parameters used in this method are calculated by using the formulas given below:

$$m = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum(x^2)) - (\sum x)^2} \quad (3.7)$$

$$b = \frac{(\sum y)(\sum(x^2)) - (\sum x)(\sum xy)}{n(\sum(x^2)) - (\sum x)^2} \quad (3.8)$$

where;

m : Slope of the linear equation (capita/year)

b : Constant of the linear equation (capita)

x : Time period since the first population census (year)

y : Results of population census (capita)

n : Number of the population census

After the calculations of the constants, the population values for the future are calculated by the formulas given below :

$$y = b + (m \times x) \quad (3.9)$$

The calculation results are given in Table 3.4a. In this table y_1, y_2 and y_3 represent the population of the Centrum, Erfelek and Gerze, respectively.

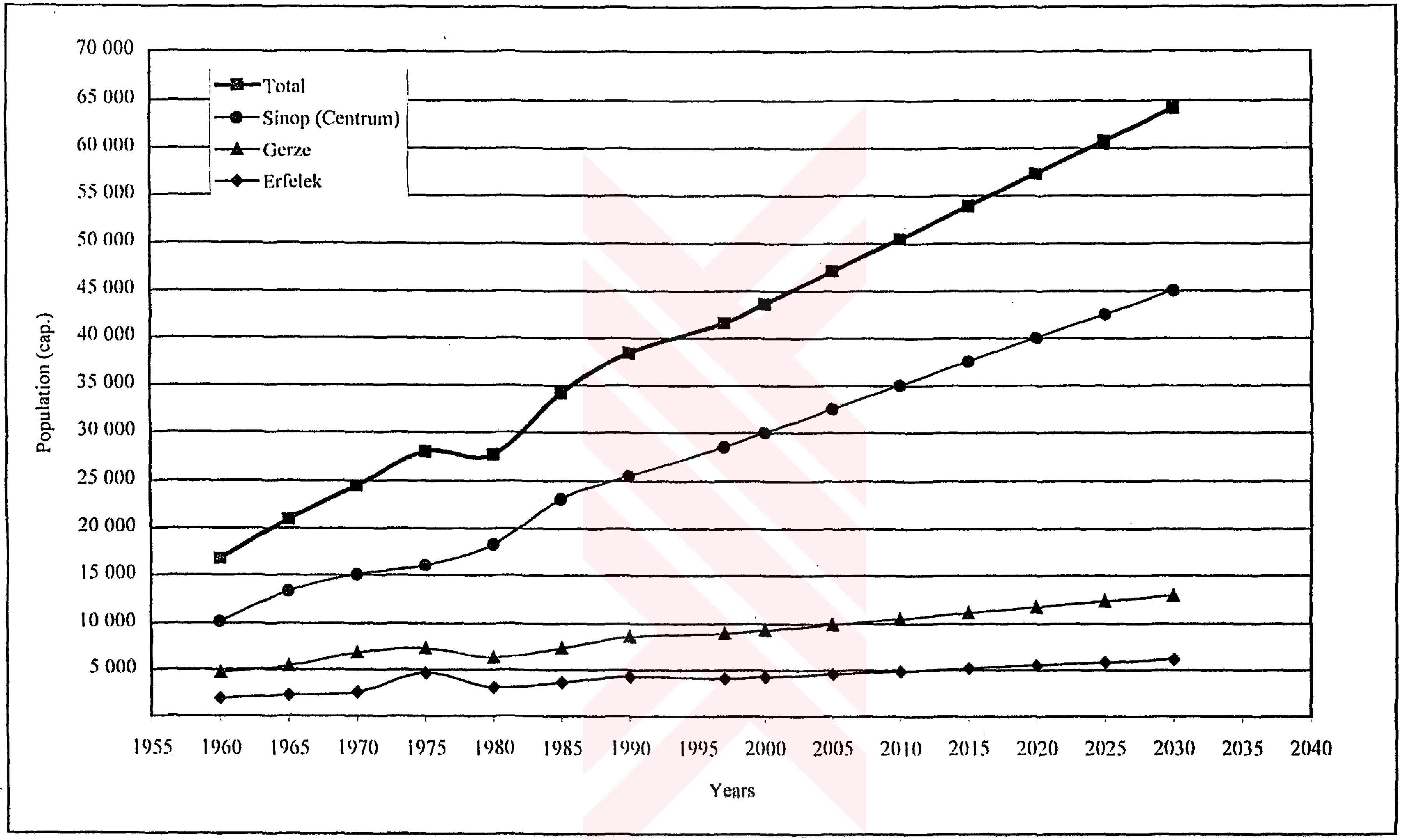


Figure 3.3. The future population projection according to the arithmetic increase

Table 3.4a. Linear regression coefficients

Years	x	y_1	y_2	Y_3	xy_1	xy_2	xy_3	x^2
1960	0	10.214	1.890	4.680	0	0	0	0
1965	5	13.354	2.244	5.387	66.770	11.220	26.935	25
1970	10	15.096	2.554	6.823	150.960	25.540	68.230	100
1975	15	16.098	4.634	7.313	241.470	69.510	109.695	225
1980	20	18.328	3.066	6.327	366.560	61.320	126.540	400
1985	25	23.148	3.672	7.370	578.700	91.800	184.250	625
1990	30	25.537	4.262	8.609	766.110	127.860	258.270	900
1997	37	28.574	4.072	8.976	1.057.238	150.664	332.112	1.369
Total	**142**	**150.349**	**26.394**	**55.485**	**3.227.808**	**537.914**	**1.106.032**	**3 644**

By the same steps, *m* and *b* (1, 2, 3) are calculated as below :

$$m_1 = \frac{(8 \times 3\,227\,808) - (142 \times 150\,349)}{(8 \times 3\,644) - 142^2} = 497.65$$

$$m_2 = \frac{(8 \times 537\,914) - (142 \times 26\,394)}{(8 \times 3\,644) - 142^2} = 61.79$$

$$m_3 = \frac{(8 \times 1\,106\,032) - (142 \times 55\,485)}{(8 \times 3\,644) - 142^2} = 107.85$$

$$b_1 = \frac{(150\,349 \times 3\,644) - (142 \times 3\,227\,808)}{(8 \times 3\,644) - 142^2} = 9{,}960.28$$

$$b_2 = \frac{(26\,394 \times 3\,644) - (142 \times 537\,914)}{(8 \times 3\,644) - 142^2} = 2{,}202.49$$

$$b_3 = \frac{(55\,485 \times 3\,644) - (142 \times 1\,106\,032)}{(8 \times 3\,644) - 142^2} = 5{,}021.23$$

Population projections according to linear regression is given in Table 3.4b.

Table 3.4b. Population projections according to linear regression

Years	Centrum	Erfelek	Gerze	Total
2000	= 497.65 x (2000- 1960) + 9960.28 = 29.866	= 61.79 x (2000- 1960) + 2202.49 = 4.674	= 107.85 x (2000- 1960) + 5021.23 = 9.335	43.875
2005	= 497.65 x (2005- 1960) + 9960.28 = 32.355	= 61.79 x (2005- 1960) + 2202.49 = 4.983	= 107.85 x (2005- 1960) + 5021.23 = 9.875	47.213
2010	= 497.65 x (2010- 1960) + 9960.28 = 34.843	= 61.79 x (2010- 1960) + 2202.49 = 5.292	= 107.85 x (2010- 1960) + 5021.23 = 10.414	50.549
2015	= 497.65 x (2015- 1960) + 9960.28 = 37.331	= 61.79 x (2015- 1960) + 2202.49 = 5.601	= 107.85 x (2015- 1960) + 5021.23 = 10.953	53.885
2020	= 497.65 x (2020- 1960) + 9960.28 = 39.819	= 61.79 x (2020- 1960) + 2202.49 = 5.910	= 107.85 x (2020- 1960) + 5021.23 = 11.492	57.221
2025	= 497.65 x (2025- 1960) + 9960.28 = 42.308	= 61.79 x (2025- 1960) + 2202.49 = 6.219	= 107.85 x (2025- 1960) + 5021.23 = 12.032	60.559
2030	= 497.65 x (2030- 1960) + 9960.28 = 44.796	= 61.79 x (2030- 1960) + 2202.49 = 6.528	= 107.85 x (2030- 1960) + 5021.23 = 12.571	63.895

Figure 3.4 depicts the populations calculated according to linear regression. It is seen that the population increases constantly and finally reaches to 67,000.

3.4. Bank of Provinces Method

In this method, population increasing coefficient between two population census is calculated by the formula given below :

$$p = [(N_y / N_e)^{1/a} - 1] \times 100 \qquad (3.10)$$

p : Population increase coefficient

N_y : The last population census (capita)

N_e : The last population census result that is taken as a basis (capita)

a : The time between the two population census (year)

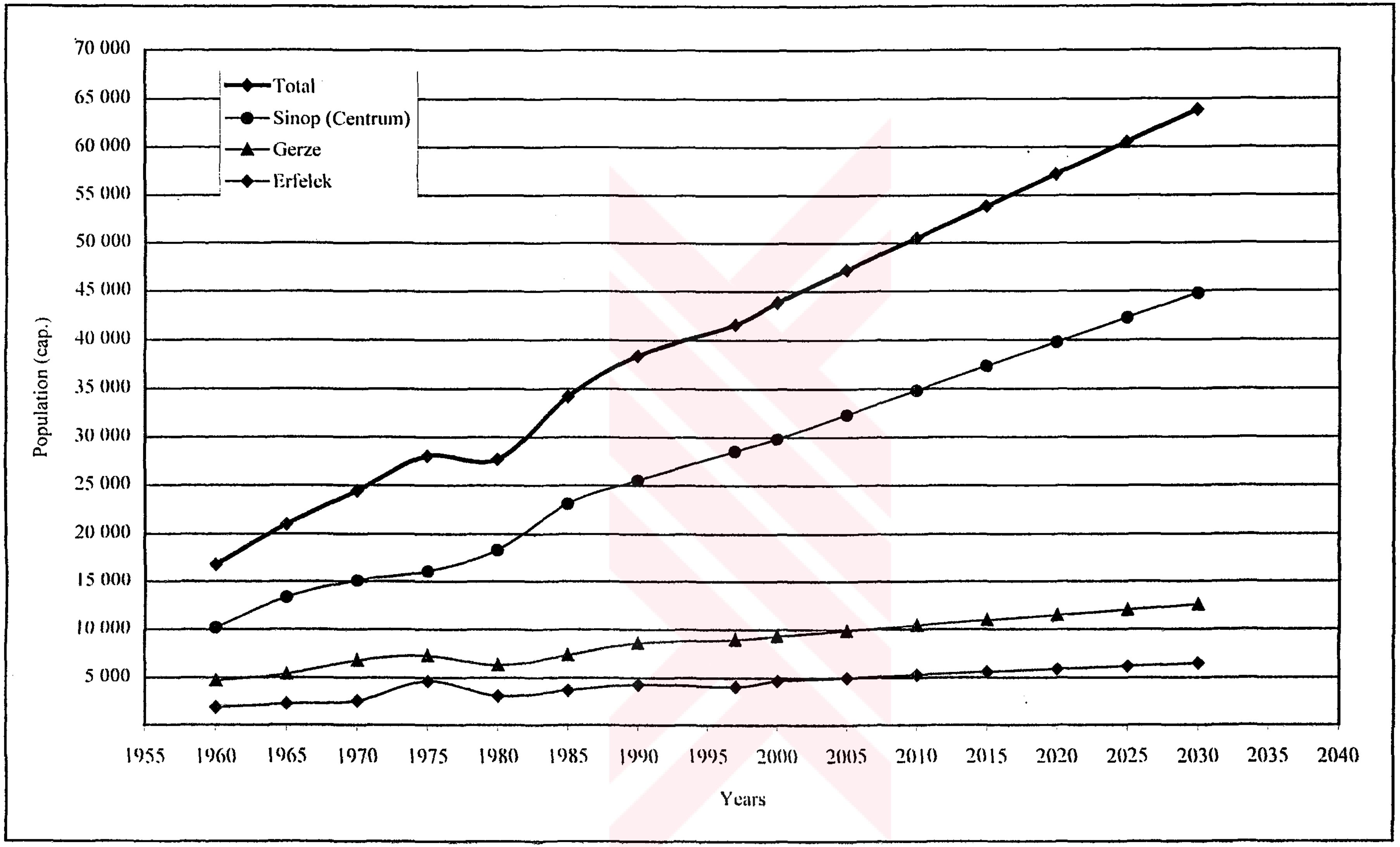


Figure 3.4. The future population projection according to the linear regression

p* which is the average of the p values is calculated as given below ;

$$p^* = (1/k) \cdot \sum_{i=1}^{k} p^i \tag{3.11}$$

k : Number of p values,

and the future population was calculated by using the formula given below :

$$N = N_y \cdot (1 + p^*/100)^n \tag{3.12}$$

N	:	Future population (capita)
N_s	:	The result of latest population census (capita)
p*	:	Population increase coefficient
n	:	The number of years till the target year (year)

The calculations of population increase coefficients for Bank of Provinces method is given in Table 3.5a. According to this method, p value is accepted as equal to 3% if it is bigger than 3%. and equal to 1% if it is smaller than 1%. In the project region. this situation was not observed, but in Erfelek this coefficient is accepted as p=1%. In Sinop (Centrum) and Gerze p values are accepted as 2.33% and 1.79% respectively. The results of the calculations are given in Table 3.5b.

Table 3.5a. Bank of Provinces method population increase coefficients

Years	Centrum (%)	Erfelek (%)	Gerze (%)
1960 – 1997	$= [(28574/10214)^{[1/(1997-1960)]}-1]x100$	$= [(4072/1890)^{[1/(1997-1960)]}-1]x100$	$= [(8976/4680)^{[1/(1997-1960)]}-1]x100$
	= 2.82	= 2.10	= 1.78
1965 – 1997	$= [(28574/13354)^{[1/(1997-1965)]}-1]x100$	$= [(4072/2244)^{[1/(1997-1965)]}-1]x100$	$= [(8976/5387)^{[1/(1997-1965)]}-1]x100$
	= 2.41	= 1.88	= 1.61
1970 – 1997	$= [(28574/15096)^{[1/(1997-1970)]}-1]x100$	$= [(4072/2554)^{[1/(1997-1970)]}-1]x100$	$= [(8976/6823)^{[1/(1997-1970)]}-1]x100$
	= 2.39	= 1.74	= 1.02
1975 – 1997	$= [(28574/16098)^{[1/(1997-1975)]}-1]x100$	$= [(4072/4634)^{[1/(1997-1975)]}-1]x100$	$= [(8976/7313)^{[1/(1997-1975)]}-1]x100$
	= 2.64	= -0.59	= 0.94
1980 – 1997	$= [(28574/18328)^{[1/(1997-1980)]}-1]x100$	$= [(4072/3066)^{[1/(1997-1980)]}-1]x100$	$= [(8976/6327)^{[1/(1997-1980)]}-1]x100$
	= 2.65	= 1.68	= 2.08
1985 – 1997	$= [(28574/23148)^{[1/(1997-1985)]}-1]x100$	$= [(4072/3672)^{[1/(1997-1985)]}-1]x100$	$= [(8976/7370)^{[1/(1997-1985)]}-1]x100$
	= 1.77	= 0.87	= 1.66
1990 – 1997	$= [(28574/25537)^{[1/(1997-1990)]}-1]x100$	$= [(4072/4262)^{[1/(1997-1990)]}-1]x100$	$= [(8976/8609)^{[1/(1997-1990)]}-1]x100$
	= 1.62	= -0.65	= 0.60
Ortalama	2.33	1.00	1.38

Table 3.5b. Population projections according to Bank of Provinces method

Years	Centrum	Erfelek	Gerze	Total
2000	= 28574x[(1+2.33/100)(2000-1997)]	= 4072x[(1+1/100)(2000-1997)]	= 8976x[(1+1.38/100)(2000-1997)]	44 166
	= 30618	= 4195	= 9353	
2005	= 28574x[(1+2.33/100)(2005-1997)]	= 4072x[(1+1/100)(2005-1997)]	= 8976x[(1+1.38/100)(2005-1997)]	48 780
	= 34355	= 4409	= 10016	
2010	= 28574x[(1+2.33/100)(2010-1997)]	= 4072x[(1+1/100)(2010-1997)]	= 8976x[(1+1.38/100)(2010-1997)]	53 910
	= 38549	= 4634	= 10727	
2015	= 28574x[(1+2.33/100)(2015-1997)]	= 4072x[(1+1/100)(2015-1997)]	= 8976x[(1+1.38/100)(2015-1997)]	59 613
	= 43254	= 4871	= 11488	
2020	= 28574x[(1+2.33/100)(2020-1997)]	= 4072x[(1+1/100)(2020-1997)]	= 8976x[(1+1.38/100)(2020-1997)]	65 954
	= 48533	= 5119	= 12302	
2025	= 28574x[(1+2.33/100)(2025-1997)]	= 4072x[(1+1/100)(2025-1997)]	= 8976x[(1+1.38/100)(2025-1997)]	73 012
	= 54457	= 5380	= 13175	
2030	= 28574x[(1+2.33/100)(2030-1997)]	= 4072x[(1+1/100)(2030-1997)]	= 8976x[(1+1.38/100)(2030-1997)]	80 868
	= 61104	= 5655	= 14109	

The population increase of the both three provinces is given in Figure 3.5. It is seen that the population increase in the region will develop and it will reach to 83,000. It is observed that this method shows similarity mostly with Geometric Increase Method. In addition, it will be safe when the fact that 'the city administrative boundaries can change in the future' has been taken into account.

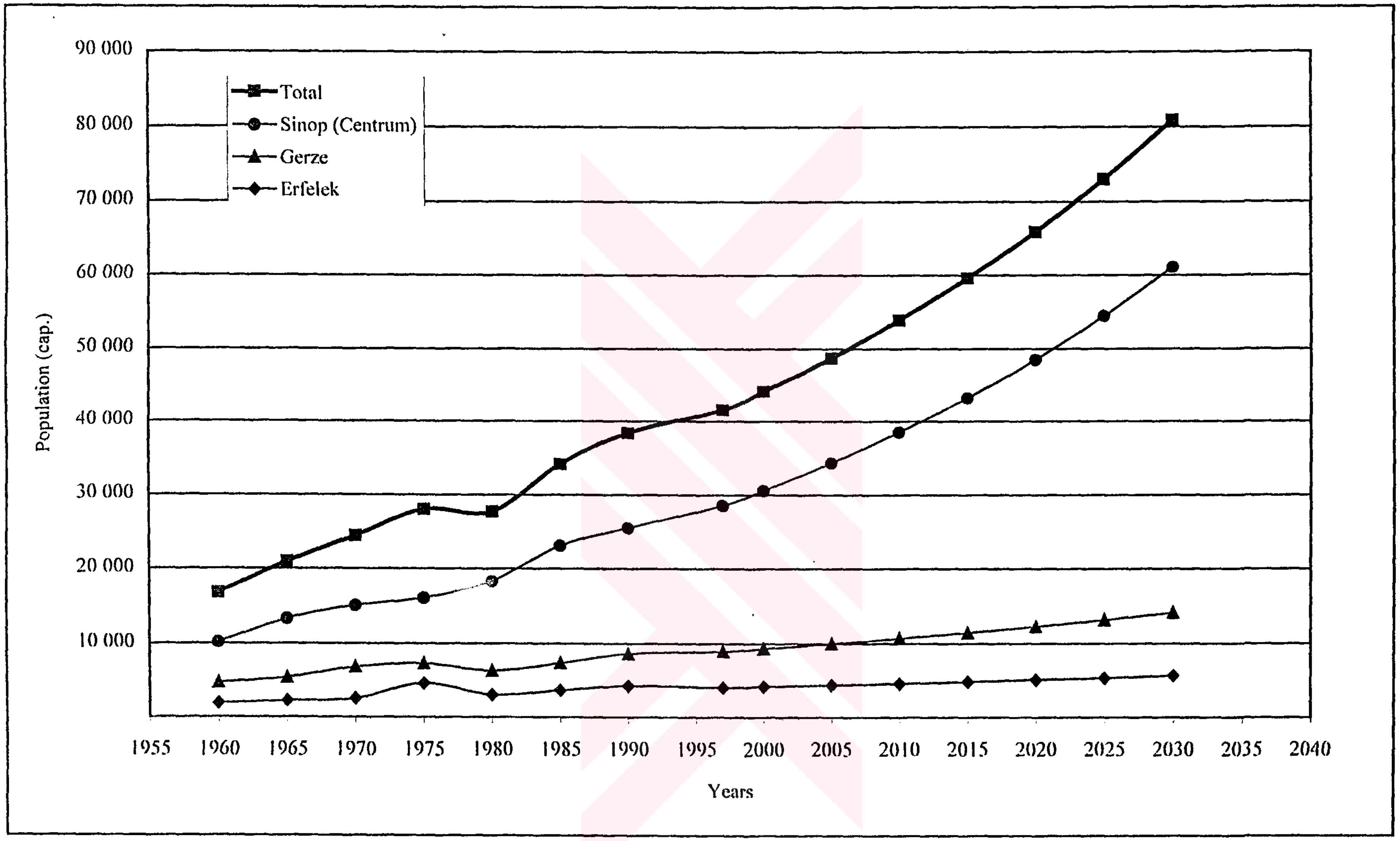


Figure 3.5. The future population projection according to the Bank of Provinces method

3.5. Evaluation of the Methods

The population calculations given in the above sections are summarised in Table 3.6.

Table 3.6. The comparison of population projection results

Method	Total Project Population		
	Year 2000	Year 2015	Year 2030
Geometric Increase Method	44.995	66.619	99.077
Arithmetic Increase Method	43.674	53.934	64.194
Linear Regression Method	43.875	53.885	63.895
Bank of Provinces Method	44.166	59.613	80.868

Comparing the results of these four methods. it is seen that the results of arithmetic increase and linear regression methods are similar to each other and their results are smaller than the other two methods. The results of geometric increase method include the highest population values. Lastly, the results of Bank of Provinces method include the average values of all four methods.

As a result, the population values calculated by Bank of Provinces method is chosen as it gives the average values compared to other three methods.

3.6. Population Estimation for Rural Areas

In the project region, there are also some rural areas that their solid wastes are collected by the municipality. The population records of these areas for the year 1997 gained from Sinop Municipality are given below :

Area	Population
Korucuk	1.597
Bostancılı	985
Akliman	160
Osmaniye	870
Total	**3,612**

The urban population of Sinop (Centrum) in 1997 is 28.574. Then, the ratio of rural area population to Sinop (Centrum) population is :

$$3,612 / 28.574 = 0.13$$

Assuming the rural population ratio over the urban population will remain the same, the future population of the rural areas of Sinop can be projected as given in Table 3.7.

Table 3.7. Rural population projections of the project area

Years	Sinop (Centrum)*	Rural Population
2000	30.618	3,980
2005	34,355	4,466
2010	38.549	5,011
2015	43,254	5,623
2020	48,533	6,309
2025	54,457	7,079
2030	61,104	7,944

* see Table 3.5b.

3.7. Population Estimation for Tourism Activity

In the region. tourism activity takes place for the three months of the year. According to data from Sinop Governorship, tourism population for summer season reaches to 75% of the urban population. In order to estimate an average coefficient, peak factor was taken as 1.75 for this season (tourism season) and taken as 1 in the rest of nine months. Then the average coefficient ($k_{aver.}$) is calculated as below ;

$$k_{aver.} = \frac{1.75 \times 3 + 9 \times 1.00}{12} = 1.19$$

The rate of increase for the tourism population is accepted equal to the rate found by Bank of Provinces Method. Then, the tourism population was calculated as 19% of population found by Bank of Provinces Method.

3.8. Total Project Population

Total projected population that was used in the design calculations includes urban, rural and tourism population. The results are given in Table 3.8.

According to these values, in the 1st Stage of the project (2015), the overall population will be 76.561, and in the 2nd Stage (2030) will be 104.177. The project population trend is also shown with a graphic in Figure 3.6.

Table 3.8. Overall summary of total project population

Years	Centrum	Erfelek	Gerze	Sub-Total	Rural Population	Touristic Population	Total Project Population
	A	B	C	D	E	F	G
				(A+B+C)	(Ax0,13)	(Dx0,19)	(A+B+C+D+E+F)
2000	**30 618**	**4 195**	**9 353**	**44 166**	**3 980**	**8 392**	**56 538**
2001	31 332	4 237	9 482	45 051	4 073	8 560	57 684
2002	32 062	4 280	9 613	45 954	4 168	8 731	58 853
2003	32 809	4 323	9 745	46 877	4 265	8 907	60 048
2004	33 573	4 366	9 880	47 819	4 365	9 086	61 269
2005	**34 355**	**4 409**	**10 016**	**48 781**	**4 466**	**9 268**	**62 516**
2006	35 156	4 453	10 154	49 764	4 570	9 455	63 789
2007	35 975	4 498	10 295	50 768	4 677	9 646	65 090
2008	36 813	4 543	10 437	51 793	4 786	9 841	66 419
2009	37 671	4 588	10 581	52 840	4 897	10 040	67 777
2010	**38 549**	**4 634**	**10 727**	**53 910**	**5 011**	**10 243**	**69 164**
2011	39 447	4 681	10 875	55 002	5 128	10 450	70 581
2012	40 366	4 727	11 025	56 118	5 248	10 662	72 028
2013	41 307	4 775	11 177	57 258	5 370	10 879	73 507
2014	42 269	4 822	11 331	58 423	5 495	11 100	75 018
2015	**43 254**	**4 871**	**11 487**	**59 612**	**5 623**	**11 326**	**76 561**
2016	44 262	4 919	11 646	60 827	5 754	11 557	78 138
2017	45 293	4 969	11 807	62 068	5 888	11 793	79 749
2018	46 348	5 018	11 970	63 336	6 025	12 034	81 395
2019	47 428	5 068	12 135	64 631	6 166	12 280	83 077
2020	**48 533**	**5 119**	**12 302**	**65 955**	**6 309**	**12 531**	**84 795**
2021	49 664	5 170	12 472	67 306	6 456	12 788	86 551
2022	50 821	5 222	12 644	68 687	6 607	13 051	88 345
2023	52 005	5 274	12 819	70 098	6 761	13 319	90 178
2024	53 217	5 327	12 996	71 540	6 918	13 593	92 050
2025	**54 457**	**5 380**	**13 175**	**73 012**	**7 079**	**13 872**	**93 964**
2026	55 726	5 434	13 357	74 517	7 244	14 158	95 919
2027	57 024	5 488	13 541	76 054	7 413	14 450	97 917
2028	58 353	5 543	13 728	77 624	7 586	14 749	99 959
2029	59 713	5 599	13 917	79 229	7 763	15 053	102 045
2030	**61 104**	**5 655**	**14 109**	**80 868**	**7 944**	**15 365**	**104 177**

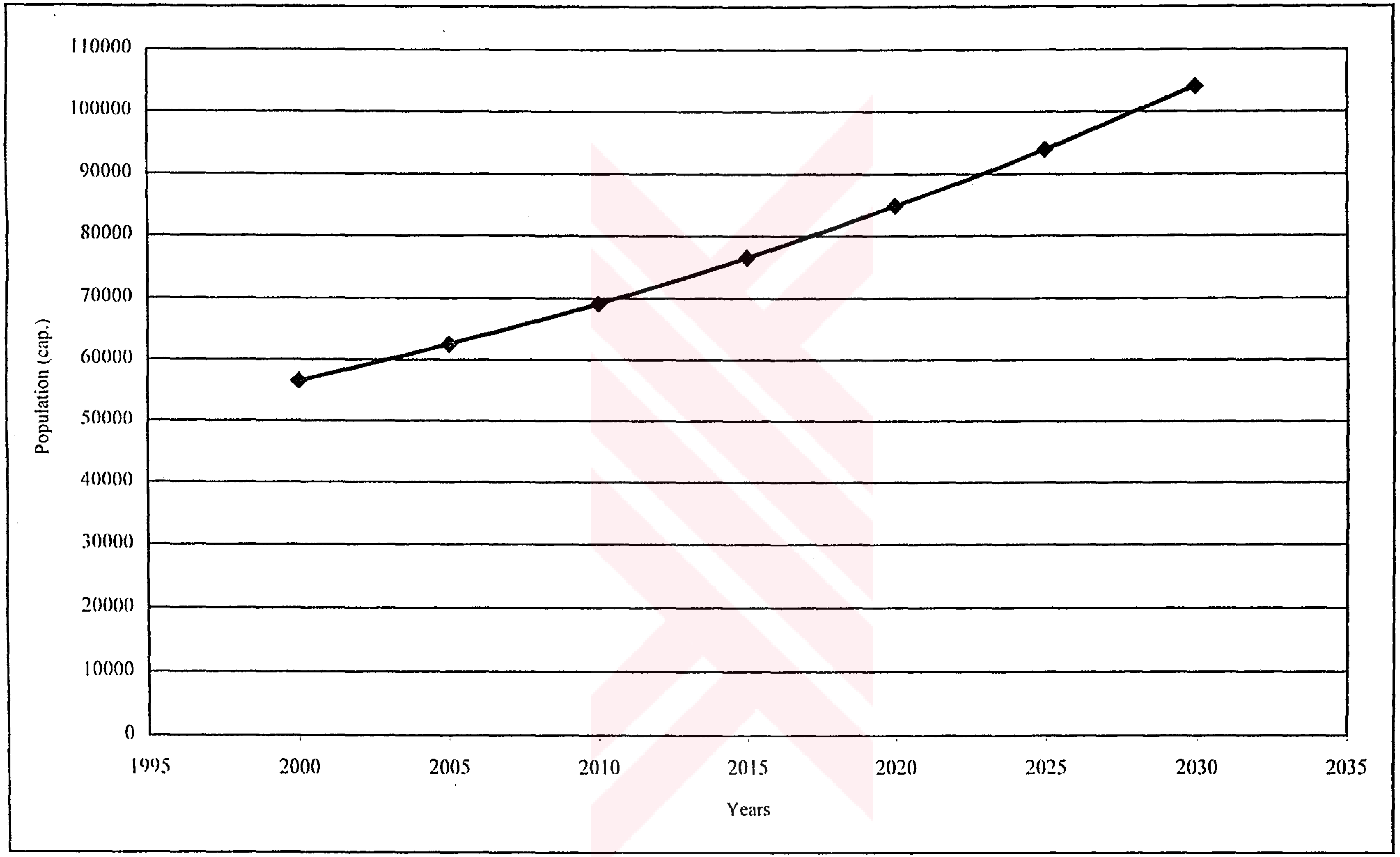


Figure 3.6. Total project population

4. CALCULATION OF SOLID WASTE QUANTITY

The quantity of the solid waste produced in the project area is the main parameter used in the design of a sanitary landfill. In the scope of this study, municipal solid wastes from residences, military services and industrial facilities. and dewatered sludge from domestic wastewater treatment plant were calculated. Additionally, the calculation of recoverable MSW and hospital waste quantities was included.

4.1. Municipal Solid Wastes from Residences

Today, there is no available data showing the existing situation about the solid waste quantity in the whole project area. These data can be obtained after a long term study. In the calculation of solid waste quantities, population projections and the unit solid waste production were used.

The quantity and quality of solid wastes show different characteristics from one country to another, from one city to another in the same country, and even from one region to another in the same city. These differences are related with the socioeconomic and sociocultural structure of the community. While deciding the amount of the unit municipal solid waste production in the project area, these factors must be taken into consideration.

Many studies have been carried out about the unit municipal solid waste production in Turkey. In these studies, many national and international sources were used. The summary of these studies and sources are given in Table 4.1.

According to these studies, unit MSW production varies between 500 – 1,800 g/cap.-day. These studies were performed for different cities in Turkey. İstanbul, İzmir and Ankara are the most populated cities of Turkey and also. the socioeconomic and sociocultural level are higher than the other cities. For this project in Sinop starting with year 2000. the unit production in Bursa and average value of Turkey is assumed to be the most representative value. "Bursa Solid Waste Project" conducted by Bursa Greater Municipality in 1991 and the study of "Solid Waste Management and Recovery in Turkey" conducted by Yüceil in

1997 indicate a unit MSW production rate of 570 g/cap.-day and 640 g/cap.-day, respectively. The study of CH_2M-ANTEL presents the increase in the rate of unit MSW production as %1, annually.

For this project, unit MSW production rate from the Yüceil's study was used. To project this value to year 2000, the annual increase rate is assumed to be equal to 1%.

Finally, in the beginning of this project (year 2000), unit MSW production is projected and assumed as 660 g/cap.-day.

Table 4.1. Unit municipal solid waste production according to different studies

Studies	Sources	Range (g/cap.-day)
İller Bankası Solid Waste Facilities Private Specification	İller Bankası.1998	500-1.000
İstanbul Solid Waste Management Research	CH_2M-ANTEL. 1992	630-800
9 Eylül University Solid Waste Research	ÇEVMER. 1992	700
Bursa Solid Waste Project	BBB. 1991	570
Ankara Solid Waste Project	ABB. 1990	580
İzmit Integrated Environmental Project	Lurgi-Vinsan. 1994	1.000
Şile-Kömürcüoda Solid Waste Facility Research Project	Öztürk vd.. 1996	700
Solid Waste Management Implementation Study	ERM-TÇT. 1995	1,170(*)
Bursa Solid Waste Characterization	Ghassan. 1987	500 – 1.800(**)
Solid Waste Management	Borat, 1995	700 – 1,000
İstanbul Leachate Research Project	Öztürk vd.. 1995	650 - 900
Solid Waste Management and Recovery in Turkey	Yüceil. 1997	640

* It reflects the total solid waste quantity.

** It reflects the value for less developed and industrialized countries.

The calculations of the solid waste production rates in the project area cover the years between 2000 and 2030. By the increase in the socio-economical level, the consumption habits of the people in the project area change and the solid waste production increases. In some researches, this rate was found as 1% annually (CH2M Hill-Antel, 1992). Consequently, the solid waste quantity for every year can be calculated by the formula given below ;

$$W = N \times w \times f \times p^{(t_f - t_i)} \quad (4.1)$$

W : Municipal solid waste quantity (tonnes/year)

N : Population (capita)

w : Unit municipal solid waste production at the time t_i (g/cap./day)

f : Unit changing factor (365 year/day x 10^{-6} tonnes/g)

p : Annual MSW production increasing rate ($cap^{1/year}$)

t_f : The date that the MSW quantity will be calculated (year)

t_i : The initial date that the MSW quantity will be calculated (year)

Then MSW production in 2030 will be;

660 g/cap./day x $1.01^{(2030-2000)} \cong$ 890 g/cap./day

104 177 cap. x 890 g/cap./day x $10^{-6} \cong$ 92.7 tonnes/day

92.7 tonnes/day x 365 year/day $\cong$ 33 836 tonnes/year

Another important parameter in the design of the solid waste landfilling area is the unit volume weight of the MSW. As a result of the literature survey about the unit MSW volume weight, the study of Samsun Ondokuz Mayıs University was taken as a source. In this study, the change in the MSW unit volume weight in Sinop (Centrum) was determined. The result data of this study is given in Table 4.2.

Table 4.2. Monthly change of municipal solid wastes unit volume weight in Sinop (Centrum) (Ergun et al., 1997)

Months	**Unit Volume Weight (tonnes/m³)**	**Months**	**Unit Volume Weight (tonnes/m³)**	**Months**	**Unit Volume Weight (tonnes/m³)**
January	0.1786	May	0.1397	September	0.1721
February	0.1706	June	0.1437	October	0.1835
March	0.1638	July	0.1629	November	0.1805
April	0.1379	August	0.1721	December	0.1828
Average	**0.1628**				

The annual MSW production from residences is given in Table 4.3.

4.2. Municipal Solid Wastes from Industries

Unit MSW production rates change when the non-hazardous MSW from industrial sources are also included. The amount of MSW per employer in different industrial types have been estimated in many studies and the results are given in Table 4.4. The type of the industries in the project area and the number of the employer for each one was determined (Ergun et al., 1997), then the quantity of the MSW was calculated. The results of these studies are given in Table 4.4.

Table 4.3. Annual municipal solid waste production from residences

Year	Total Project Population	Daily Unit MSW Production	Daily MSW Production	MSW from Residences
	capita	gr/cap-day	tonnes/day	tonnes/year
A	B	C	D	E
A	B	$K1x(1+K2)^{(A-2000)}$	$BxCx10^{-6}$	Dx365
2000	**56 538**	**660**	**37,3**	**13 620**
2001	57 684	667	38,5	14 035
2002	58 853	673	39,6	14 463
2003	60 048	680	40,8	14 904
2004	61 269	687	42,1	15 359
2005	**62 516**	**694**	**43,4**	**15 828**
2006	63 789	701	44,7	16 312
2007	65 090	708	46,1	16 811
2008	66 419	715	47,5	17 326
2009	67 777	722	48.9	17 857
2010	**69 164**	**729**	**50,4**	**18 405**
2011	70 581	736	52,0	18 970
2012	72 028	744	53,6	19 552
2013	73 507	751	55,2	20 153
2014	75 018	759	56,9	20 773
2015	**76 561**	**766**	**58,7**	**21 412**
2016	78 138	774	60,5	22 072
2017	79 749	782	62,3	22 752
2018	81 395	789	64,3	23 454
2019	83 077	797	66,2	24 178
2020	**84 795**	**805**	**68,3**	**24 925**
2021	86 551	813	70,4	25 696
2022	88 345	822	72,6	26 490
2023	90 178	830	74,8	27 310
2024	92 050	838	77,1	28 156
2025	**93 964**	**846**	**79,5**	**29 029**
2026	95 919	855	82.0	29 929
2027	97 917	863	84,5	30 858
2028	99 959	872	87,2	31 817
2029	102 045	881	89.9	32 806
2030	**104 177**	**890**	**92,7**	**33 826**

K1 Unit MSW in year 2000; 660 g/cap-day

K2 Annual rate of increase in consumption; 1 %

Table 4.4. Municipal solid waste production from different industrial types (CH2M Hill-Antel. 1992)

Industrial Type	**MSW Production per Employer (tonnes/employer/year)**	**Total Employer (employer)**	**MSW Production (tonnes/year)**
Fish	0.4	70	28.0
Byscle	0.5	50	45.0
Food	0.4	10	4.0
Animal	0.4	15	6.0
Forest/Wood	0.5	38	19.0
Textile	0.3	700	210.0
Tobacco	0.2	406	81.2
Flour	0.2	21	4.2
Total		**1.310**	**377.0**
Average = 377 / 1310 = 0.29 tonnes/employer/year			

<u>Sinop Organized Industrial Area</u>

Sinop Organized Industrial Area is an important industrial waste source in the region. It is estimated that 4.000 employers will work here in the future (Ergun et al., 1997). There will be different types of industries in this area. When the average value in Table 4.4 is assumed as reference, then the amount of the MSW from organized industrial area will be;

4,000 employers x 0.29 tonnes/employer/year = 1,160 tonnes/year

Then, the total amount produced by industrial sources will be;

377 tonnes/year + 1,160 tonnes/year = 1,537 tonnes/year

Today, industrial sources are operated by 53% of their total capacity. In the future, when the capacity reaches to 100%, the total amount of the solid waste will be;

377 tonnes/year / 0.53 ≅ 711 tonnes/year

This increase is expected to occur between the years 2000 and 2030. Then the annual increase in the solid waste production from the industries can be estimated as;

(711 tonnes/year - 377 tonnes/year) / (2030 - 2000) = 11.13 tonnes/year

Assuming that the Organized Industrial Area will work with full capacity, then the annual total solid wastes production from industrial sources can be calculated with the formula given below;

$$W_s = 377 + 11.13 \times (t - 2000) + 1\,160 \qquad (4.2)$$

W_s = Total industrial wastes (tonnes/year)

t = Year

The estimated annual MSW production from the industries is given in Table 4.5.

Table 4.5. Annual municipal solid wastes production from industries

Year	MSW from Organized Industrial Area	MSW from Industries	Total MSW from Industries
	tonnes/year	tonnes/year	tonnes/year
A	B	C	D
A	B	K1+[K2x(A-2000)]	B+C
2000	**1160**	**377**	**1 537**
2001	1160	388	1 548
2002	1160	399	1 559
2003	1160	410	1 570
2004	1160	422	1 582
2005	**1160**	**433**	**1 593**
2006	1160	444	1 604
2007	1160	455	1 615
2008	1160	466	1 626
2009	1160	477	1 637
2010	**1160**	**488**	**1 648**
2011	1160	499	1 659
2012	1160	511	1 671
2013	1160	522	1 682
2014	1160	533	1 693
2015	**1160**	**544**	**1 704**
2016	1160	555	1 715
2017	1160	566	1 726
2018	1160	577	1 737
2019	1160	588	1 748
2020	**1160**	**600**	**1 760**
2021	1160	611	1 771
2022	1160	622	1 782
2023	1160	633	1 793
2024	1160	644	1 804
2025	**1160**	**655**	**1 815**
2026	1160	666	1 826
2027	1160	678	1 838
2028	1160	689	1 849
2029	1160	700	1 860
2030	**1160**	**711**	**1 871**

K1 Waste(domestic) prod. from industries in year 2000 (excluding Org.Ind.Area); 377 ton/year

K2 Annual rate of increase in SW (domestic) from industries; 11.13 ton/year

4.3. Municipal Solid Wastes from Military Services

Within the Erfelek Municipality boundary, the MSW from the military facility was also included. The wastes from that facility are collected with 150 litres containers twice a day (Ergun et al., 1997). By accepting the unit volume weight of the compressed solid waste as 0.163 tonnes/m³ , the amount of the solid waste is;

$2 \times 150\ lt \times 10^{-3}\ m^3/lt \times 0.163\ tonnes/m^3 = 0.05\ tonnes/day$

In addition to the Erfelek military facility, according to the data taken from Sinop Municipality, there is another military zone named Radar. Everyday, large amount of solid waste is collected with 5 tonnes uncompacted vehicles. Consequently, the MSW from this zone is;

$5\ m^3 \times 0.163\ tonnes/m^3 = 0.82\ tonnes/day$

Then the total municipal solid wastes from military facilities is estimated to be :

$0.05\ tonnes/day + 0.82\ tonnes/day = 0.87\ tonnes/day$

It is estimated that wastes from military facilities will increase at a rate of 20% at the end of the project (Ergun et al., 1997). Then the annual increase will be;

$(0.87\ tonnes/day \times 0.20) / (2030 - 2000) \times 365\ day/year \cong 2\ tonnes/year$

The estimated annual MSW production from Military Services is given in Table 4.6.

Table 4.6. Annual municipal solid wastes production from military services

Year	MSW from Military Services
	tonnes/year
A	**B**
A	**(K1x365)+[K2x(A-2000)]**
2000	**318**
2001	320
2002	322
2003	324
2004	326
2005	**328**
2006	330
2007	332
2008	334
2009	336
2010	**338**
2011	340
2012	342
2013	344
2014	346
2015	**348**
2016	350
2017	352
2018	354
2019	356
2020	**358**
2021	360
2022	362
2023	364
2024	366
2025	**368**
2026	370
2027	372
2028	374
2029	376
2030	**378**

K1 Wastes from military services in yaer 2000: 0.87 tonnes/day

K2 Annual rate of increase in military servives; 2 tonnes/year

4.4. Sludge from Treatment Facilities

The primary wastewater treatment and sea discharge facilities for Sinop (Centrum) was investigated as a potential source waste generation since there is a tendency for landfilling of the treatment sludge. "Istanbul Water Supply, Sewerage and Drainage, Sewage Treatment and Disposal Master Plan" study indicates the unit sludge production rate of 11.28 g/cap/day (dry weight) after primary treatment (İstanbul Master Plan Concortium, 1999). This value is valid for the primary treatment facility including "Screening"; "Grit Chamber"; "Gravity Thickening"; "Anaerobic Sludge Stabilization" and "Centrifugal Dewatering" processes. With a conjection of the other municipalities, a similar treatment facility will be constructed in Sinop, in the future. Accordingly, the annual treatment sludge was calculated. As an example, the sludge production in year 2030 will be:

$$104{,}177 \text{ cap.} \times 11.28 \text{ g/cap./day} \times 10^{-3} \text{ kg/g} \cong 1{,}175 \text{ kg/day}$$
$$\cong 429 \text{ tonnes/year}$$

According to the current "Solid Waste Control Regulations", domestic wastewater sludge can be disposed with municipal solid wastes if sufficient dewatering (minimum 35% solid content) is applied (Turkish Solid Waste Regulation, 1991).

The estimated annual sludge production is given in Table 4.7.

4.5. Recoverable Municipal Solid Wastes (RMSW)

The recovery of RMSW is not projected in the scope of this study. However, only the amount of potential RMSW is determined.

In the studies that was performed by Samsun Ondokuz Mayıs University, material distribution in municipal solid wastes was examined for Sinop (Centrum). The solid waste characteristics of the other provinces were also examined and it was seen that there was no significant difference. Therefore, the characteristics of the solid waste for Sinop (Centrum), Gerze and Erfelek are assumed to be the same (Ergun et al., 1997). As a result of this study, the material distribution in the solid waste is calculated and given in Figure 4.1.

Table 4.7. Annual sludge production

Year	Total Project Population	Treatment Sludge
	capita	tonnes/year
A	B	C
A	B	$BxK1x365x10^{-6}$
2000	**56 538**	**233**
2001	57 684	237
2002	58 853	242
2003	60 048	247
2004	61 269	252
2005	**62 516**	**257**
2006	63 789	263
2007	65 090	268
2008	66 419	273
2009	67 777	279
2010	**69 164**	285
2011	70 581	291
2012	72 028	297
2013	73 507	303
2014	75 018	309
2015	**76 561**	**315**
2016	78 138	322
2017	79 749	328
2018	81 395	335
2019	83 077	342
2020	**84 795**	**349**
2021	86 551	356
2022	88 345	364
2023	90 178	371
2024	92 050	379
2025	**93 964**	**387**
2026	95 919	395
2027	97 917	403
2028	99 959	412
2029	102 045	420
2030	**104 177**	**429**

K1 Unit primary treatment sludge production; 11.28 g/cap-day

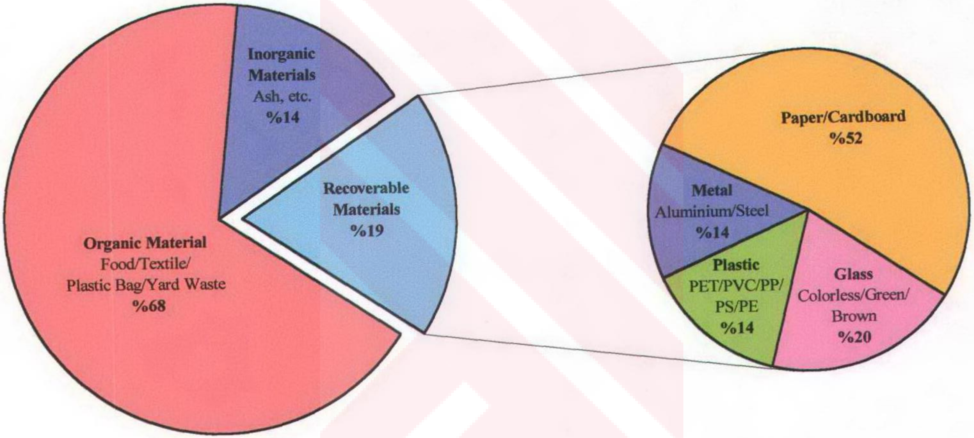


Figure 4.1. Recoverable material distribution in Sinop(Centrum) municipal solid wastes (Ergun et al., 1997)

According to this distribution, the rate of RMSW is 18%. During the separation of RMSW from MSW and to get clean RMSW there will be some losses. These losses are given below:

- Many recoverable materials (especially paper and cardboard) lose their recoverability if they are not stored and collected seperately. In addition, some losses may occur during the unefficient collection. This rate is about 30%.

- Second type of losses occur during the transportation before the last separation and storage. All of the wastes may not be collected and transported; some of them may become contaminated during the storage period; and sometimes they are not classified correctly. All of these losses include a rate of 15%.

- Finally, while the weighting & classification of recoverable material and the processing period at the facility some losses may occur. These losses include a rate of 25%.

By using these three rates, the efficiency of recovery in Sinop was determined. The efficient recovery rate of the RMSW is;

$$(1.00 - 0.30) \times (1.00 - 0.15) \times (1.00 - 0.25) = 0.45 \ (45\%)$$

Then the efficient recovery rate of the MSW is;

$$0.18 \times 0.45 \cong 0.08 \ (8\%)$$

The results of the calculation of RMSW production is given in Table 4.8.

Table 4.8. Recoverable municipal solid wastes production

Year	The Amount of Potential RMSW tonnes/year	Net Amount of RMSW tonnes/year	Recoverable Paper tonnes/year	Recoverable Plastic tonnes/year	Recoverable Metal tonnes/year	Recoverable Glass tonnes/year	Amount of Potential RMSW (Cumulative) tonnes/year	Amount of Net RMSW (Cumulative) tonnes/year
A	B	C	D	E	F	G	H	I
A	B	NxK1xK2xK3	OxK4	OxK5	OxK6	OxK7	S(B)	S(C)
2000	**2 452**	**1 094**	**481**	**186**	**186**	**241**	**2 452**	**1 094**
2001	2 526	1 127	496	192	192	248	4 978	2 221
2002	2 603	1 162	511	197	197	256	7 581	3 383
2003	2 683	1 197	527	204	204	263	10 264	4 580
2004	2 765	1 234	543	210	210	271	13 029	5 814
2005	**2 849**	**1 271**	**559**	**216**	**216**	**280**	**15 878**	**7 085**
2006	2 936	1 310	577	223	223	288	18 814	8 396
2007	3 026	1 350	594	230	230	297	21 840	9 746
2008	3 119	1 392	612	237	237	306	24 959	11 138
2009	3 214	1 434	631	244	244	316	28 173	12 572
2010	**3 313**	**1 478**	**650**	**251**	**251**	**325**	**31 486**	**14 050**
2011	3 415	1 524	670	259	259	335	34 900	15 574
2012	3 519	1 571	691	267	267	346	38 420	17 145
2013	3 628	1 619	712	275	275	356	42 047	18 764
2014	3 739	1 669	734	284	284	367	45 786	20 432
2015	**3 854**	**1 720**	**757**	**292**	**292**	**378**	**49 641**	**22 152**
2016	3 973	1 773	780	301	301	390	53 613	23 925
2017	4 095	1 828	804	311	311	402	57 709	25 753
2018	4 222	1 884	829	320	320	414	61 931	27 637
2019	4 352	1 942	855	330	330	427	66 283	29 579
2020	**4 487**	**2 002**	**881**	**340**	**340**	**440**	**70 769**	**31 581**
2021	4 625	2 064	908	351	351	454	75 394	33 645
2022	4 768	2 128	936	362	362	468	80 163	35 773
2023	4 916	2 194	965	373	373	483	85 079	37 966
2024	5 068	2 262	995	384	384	498	90 147	40 228
2025	**5 225**	**2 332**	**1 026**	**396**	**396**	**513**	**95 372**	**42 560**
2026	5 387	2 404	1 058	409	409	529	100 759	44 964
2027	5 555	2 479	1 091	421	421	545	106 314	47 443
2028	5 727	2 556	1 124	434	434	562	112 041	49 998
2029	5 905	2 635	1 159	448	448	580	117 946	52 633
2030	**6 089**	**2 717**	**1 196**	**462**	**462**	**598**	**124 034**	**55 350**

K1 Efficiency of RMSW Collection; %70
K2 Efficiency of RMSW Transportation; %85
K3 Efficiency of RMSW Seperation; %75
K4 Rate of Paper to Total RMSW; %44
K5 Rate of Plastic to Total RMSW; %17
K6 Rate of Metal to Total RMSW;%17
K7 Rate of Glass to Total RMSW, %22

4.6. Hospital Wastes

The disposal of hospital wastes is not projected in the scope of this project. However, the amount of hospital wastes that will be produced in the project site is determined.

According to the criteria in Bank of Provinces Specification, the production of hospital wastes is assumed to be 2.5 kg/bed/day. This amount also includes the wastes produced by the employers in the hospital. The list of the sanitary facilities in the project area is given in Table 4.9. The list reflects the records in 1998.

Table 4.9. Sanitary facilities in the project area in 1998 (Ergun et al., 1997)

Sanitary Facilities	Bed Capacity
Sinop Atatürk Hospital	189
Sinop SSK Hospital	107
Gerze Sanitary Center	15
Gerze Hospital (planned)	60
Erfelek Hospital (planned)	50
TOTAL	**421**

Consequently, in the beginning of the project (year 2000) the amount of the hospital wastes is estimated to be ;

2.5 kg/bed/day x 421 day ≅ 1,053 kg/day

For the calculation of future sanitary solid waste production, the rate of increase is taken equal with the project population increasing rate. Then, the future amount is calculated as below ;

$$W_m = N_t / N_{2000} \cdot W_{m_{2000}} \tag{4.3}$$

W_m : The amount of sanitary solid waste (tonnes/year)

N_t : Project population in a given year (capita)

N_{2000} : Year 2000 project population (capita)

$W_{m_{2000}}$: The amount of sanitary solid waste in year 2000(tonnes/year)

The results of hospital waste production are are given in Table 4.10.

In conclusion, after all these calculations, the total amount of MSW deposited in Sinop (Meşedağı) sanitary landfill is given in Table 4.11.

Table 4.10. Hospital waste production

Year	Total Project Population	Hospital Wastes (Relative)	Hospital Wastes (Cumulative)
	capita	tonnes/year	tonnes/year
A	B	M	N
A	B	K1xK2x0,365*K3	S(M)
2000	**56 538**	**384**	**384**
2001	57 684	392	776
2002	58 853	400	1 176
2003	60 048	408	1 584
2004	61 269	416	2 000
2005	**62 516**	**425**	**2 424**
2006	63 789	433	2 857
2007	65 090	442	3 300
2008	66 419	451	3 751
2009	67 777	460	4 211
2010	**69 164**	**470**	**4 681**
2011	70 581	479	5 160
2012	72 028	489	5 649
2013	73 507	499	6 149
2014	75 018	510	6 658
2015	**76 561**	**520**	**7 178**
2016	78 138	531	7 709
2017	79 749	542	8 250
2018	81 395	553	8 803
2019	83 077	564	9 368
2020	**84 795**	**576**	**9 943**
2021	86 551	588	10 531
2022	88 345	600	11 131
2023	90 178	612	11 744
2024	92 050	625	12 369
2025	**93 964**	**638**	**13 007**
2026	95 919	651	13 659
2027	97 917	665	14 324
2028	99 959	679	15 003
2029	102 045	693	15 696
2030	**104 177**	**708**	**16 403**

K1 The total number of beds in year 2000 ; 421
K2 The amount of hospital waste per bed ; 2.5 kg/bed-day
K3 Rate of population increase (N_t - N_{2000})

Table 4.11. Total amount of municipal solid wastes deposited in Sinop(Meşedağı) sanitary landfill

Year	Total Project Population	MSW from Residences	MSW from Military Services	Treatment Sludge	MSW from Industrial Facilities	Total MSW (Relative)	Total MSW (Cumulative)
	capita	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes/year	tonnes
2000	**56 538**	**13 620**	**318**	**233**	**1 537**	**15 707**	**15 707**
2001	57 684	14 035	320	237	1 548	16 140	31 848
2002	58 853	14 463	322	242	1 559	16 586	48 433
2003	60 048	14 904	324	247	1 570	17 045	65 478
2004	61 269	15 359	326	252	1 582	17 518	82 997
2005	**62 516**	**15 828**	**328**	**257**	**1 593**	**18 006**	**101 003**
2006	63 789	16 312	330	263	1 604	18 508	119 511
2007	65 090	16 811	332	268	1 615	19 026	138 536
2008	66 419	17 326	334	273	1 626	19 559	158 096
2009	67 777	17 857	336	279	1 637	20 109	178 204
2010	**69 164**	**18 405**	**338**	**285**	**1 648**	**20 675**	**198 880**
2011	70 581	18 970	340	291	1 659	21 259	220 139
2012	72 028	19 552	342	297	1 671	21 861	242 000
2013	73 507	20 153	344	303	1 682	22 481	264 481
2014	75 018	20 773	346	309	1 693	23 120	287 601
2015	**76 561**	**21 412**	**348**	**315**	**1 704**	**23 779**	**311 380**
2016	78 138	22 072	350	322	1 715	24 458	335 839
2017	79 749	22 752	352	328	1 726	25 158	360 997
2018	81 395	23 454	354	335	1 737	25 880	386 877
2019	83 077	24 178	356	342	1 748	26 624	413 502
2020	**84 795**	**24 925**	**358**	**349**	**1 760**	**27 391**	**440 893**
2021	86 551	25 696	360	356	1 771	28 182	469 075
2022	88 345	26 490	362	364	1 782	28 998	498 073
2023	90 178	27 310	364	371	1 793	29 838	527 911
2024	92 050	28 156	366	379	1 804	30 705	558 616
2025	**93 964**	**29 029**	**368**	**387**	**1 815**	**31 599**	**590 215**
2026	95 919	29 929	370	395	1 826	32 520	622 735
2027	97 917	30 858	372	403	1 838	33 471	656 205
2028	99 959	31 817	374	412	1 849	34 450	690 656
2029	102 045	32 806	376	420	1 860	35 461	726 117
2030	**104 177**	**33 826**	**378**	**429**	**1 871**	**36 503**	**762 620**

5. WASTE PROPERTIES

5.1. Sources of Solid Wastes

Knowledge of the sources and types of solid wastes, along with data on the composition and rates of generation, is basic to design and operation of the functional elements associated with the management of solid wastes (Tchobanoglous et al.. 1993).

As it was mentioned in Section 4, the sources of the wastes that will be deposited in Sinop (Meşedağı) include;

- Residences
- Industries (only MSW)
- Military Services (only non-hazardous MSW)
- Sludge from Domestic Wastewater Treatment Facility (Dewatered; minimum 35% solid content)

5.2. Types of Solid Wastes

The types of solid wastes that will be deposited in Sinop(Meşedağı) Sanitary Landfill are ;

- Food wastes
- Papers
- Plastics
- Textiles
- Woods
- Metals
- Dirt, ash, etc.
- Sludge

5.3. Waste Composition

Composition is the term used to describe the individual components that make up a solid waste stream and their relative distribution, usually based on percent by weight.

Information on the composition of solid wastes is important in evaluating equipment needs, systems, and management programs and plans (Tchobanoglous et al., 1993).

Typical physical composition of Residential MSW in the U.S., Sinop and İstanbul are given in Table 5.1.

Table 5.1. Typical physical composition of residential municipal solid wastes in the U.S., Sinop and İstanbul

	Percent by Weight			
	United States(1)		Sinop(2)	İstanbul(3)
Component	**Range**	**Typical**	**Average**	**Average**
Organic				
Food Wastes	6-18	9.0	54.19	48.0
Paper	25-40	34.0	9.66	8.4
Cardboard	3-10	6.0	-	-
Plastics	4-10	7.0	7.90	11.0
Textiles	0-4	2.0	7.20	2.9
Rubber	0-2	0.5	-	-
Leather	0-2	0.5	-	-
Yard Wastes	5-20	18.5	-	-
Wood	1-4	2.0	0.46	-
Misc. organics	-	-	0.41	3.2
Inorganic				
Glass	4-12	8.0	3.67	4.6
Tin Cans	2-8	6.0	-	2.3
Aluminum	0-1	0.5	-	-
Other Metal	1-4	3.0	2.54	6.3
Dirt, ash, etc.	0-6	3.0	13.97	13.3
TOTAL	100	100	100	100

(1) (Tchobanoglous et al., 1993)

(2) (Ergun et al., 1997). The analysis have been performed with 100 kg solid waste sample.

(3) (Demir et al., 1999)

According to these data, the organic content of the wastes in Sinop, İstanbul and the United States is 79.82%, 73.5% and 79.5%, respectively. The differences are largely due to improved food processing techniques and the increased use of kitchen food waste grinders, the increased use of plastics for food packaging and other packaging, and the fact that the burning of yard wastes is no longer available in most communities. The most significant differences between the wastes of Sinop, İstanbul and the U.S. is that food wastes content in Sinop is 54.19% when it is 48% in İstanbul and 9% in the U.S. This is due to the use of kitchen food waste grinders in the U.S. Also, in the U.S. the content of paper and yard waste are very high. However, the total organic content of the waste in Sinop is similar to the organic content in the wastes of U.S.

5.4. Physical, Chemical and Biological Properties of Solid Waste

Physical, chemical and biological properties must be known to develop and design integrated solid waste management systems (Tchobanoglous et al., 1993).

Important physical characteristics of MSW include specific weight, moisture content, particle size and size distribution, field capacity, and compacted waste porosity (Tchobanoglous et al., 1993). Typical specific weight and moisture content data for residential MSW is given in Table 5.2.

Table 5.2. Typical specific weight and moisture content data for residential wastes (Tchobanoglous et al., 1993)

Component	Specific Weight, kg/m^3		Moisture Content, %by Weight	
	Range	Typical	Range	Typical
Residential(uncompacted)				
Food Wastes(mixed)	130-480	285	50-80	70
Paper	42-131	89	4-10	6
Cardboard	4-80	50	4-8	5
Plastics	42-78	65	1-4	2
Textiles	42-101	65	6-15	10
Rubber	101-202	131	1-4	2
Leather	101-261	160	8-12	10
Yard Wastes	59-225	101	30-80	60
Wood	131-320	237	15-40	20
Glass	160-481	196	1-4	2
Tin Cans	50-160	89	2-4	3
Aluminum	65-240	160	2-4	2
Other Metal	131-1151	320	2-4	3
Dirt, ash, etc.	320-1000	481	6-12	8
Ash	650-830	745	6-12	6
Rubbish	89-181	131	5-20	15
Residential Yard Wastes				
Leaves (loose and dry)	30-148	59	20-40	30
Green Grass (loose and moist)	208-297	237	40-80	60
Green Grass (wet and compacted)	593-831	593	50-90	80
Yard Waste (shredded)	267-356	297	20-70	50
Yard Waste (composted)	267-386	326	40-60	50

Table 5.1 reflects the wet weight of the MSW in Sinop. To calculate the dry weight, moisture content of the MSW must be known. So, the typical moisture content data given in Table 5.2 is used to calculate the dry weight of organic and inorganic components of Sinop's MSW. The results are given in Table 5.3.

Table 5.3. Physical composition of residential municipal solid wastes in Sinop (Ergun et al., 1997)

Component	Percent by Weight[1], % (A)	Moisture Content[2], % (B)	Dry Weight, kg [A x (1-B)]
Organic			
Food Wastes	54.19	70	16.26
Paper	9.66	6	9.08
Cardboard	-	-	-
Plastics	7.90	2	7.74
Textiles	7.20	10	6.48
Rubber	-	-	-
Leather	-	-	-
Yard Wastes	-	-	-
Wood	0.46	20	0.37
Misc. organics	0.41	15	0.35
Inorganic			
Glass	3.67	2	3.60
Tin Cans	-	-	-
Aluminum	-	-	-
Other Metal	2.54	3	2.46
Dirt, ash, etc.	13.97	8	12.85
TOTAL	100		

(1) The observations have been carried out with 100 kg solid waste sample

(2) see Table 5.2

Information on the chemical composition of the components that constitute MSW is important in evaluating alternative processing and recovery options. The feasibility of combustion depends on the chemical composition of the solid wastes. Typically, wastes can be thought of as a combination of semimoist combustible and noncombustible materials (Tchobanoglous et al., 1993). Typical data on the ultimate analysis of individual combustible materials are presented in Table 5.4.

Table 5.4. Typical data on the ultimate analysis of the combustible materials found in residential, commercial and industrial solid wastes (Tchobanoglous et al., 1993)

Component	Percent by Weight (dry basis)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food and Food Products						
Fats	73.0	11.5	14.8	0.4	0.1	0.2
Food Wastes (mixed)	48.0	6.4	37.6	2.6	0.4	5.0
Fruit Wates	48.5	6.2	39.5	1.4	0.2	4.2
Meat Wastes	59.6	9.4	24.7	1.2	0.2	4.9
Paper Products						
Cardboard	43.0	5.9	44.8	0.3	0.2	5.0
Magazines	32.9	5.0	38.6	0.1	0.1	23.3
Newsprint	49.1	6.1	43.0	<0.1	0.2	1.5
Paper (mixed)	43.4	5.8	44.3	0.3	0.2	6.0
Waxed cartons	59.2	9.3	30.1	0.1	0.1	1.2
Plastics						
Plastics (mixed)	60.0	7.2	22.8	-	-	10.0
Polyethylene	85.2	14.2	-	<0.1	<0.1	0.4
Polystyrene	87.1	8.4	4.0	0.2	-	0.3
Polyurethane	63.3	6.3	17.6	6.0	<0.1	4.3
Polyvinyl chloride	45.2	5.6	1.6	0.1	0.1	2.0
Textiles, Rubber, Leather						
Textiles	48.0	6.4	40.0	2.2	0.2	3.2
Rubber	69.7	8.7	-	-	1.6	20.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Wood, Trees, etc.						
Yard wastes	46.0	6.0	38.0	3.4	0.3	6.3
Wood(green timber)	50.1	6.4	42.3	0.1	0.1	1.0
Hardwood	49.6	6.1	43.2	0.1	<0.1	0.9
Wood (mixed)	49.5	6.0	42.7	0.2	<0.1	1.5
Wood chips(mixed)	48.1	5.8	45.5	0.1	<0.1	0.4
Glass, Metals, etc.						
Glass and mineral	0.5	0.1	0.4	<0.1	-	98.9
Metals (mixed)	4.5	0.6	4.3	<0.1	-	90.5
Miscellaneous						
Office sweepings	24.3	3.0	4.0	0.5	0.2	68.0
Oils, paints	66.9	9.6	5.2	2.0	-	16.3
Refuse-derived Fuel	44.7	6.2	38.4	0.7	<0.1	9.9

The most important biological characteristics of the organic fraction of MSW is that almost all of the organic components can be converted biologically to gases and relatively inert organic and inorganic solids. The production of odor and the generation of flies are also related to the putrescible nature of the organic materials found in MSW (Tchobanoglous et al., 1993).

6. DESCRIPTION OF THE LANDFILL AREA, SLOPE AND BERM STABILITY ANALYSIS

6.1. Site Information

The project site on which the landfill will be constructed is located in Meşedağı, on the 12 km southwest of Sinop city centrum. The area of the site is about 16 hectars. The photograph of the site is given in Figure 6.1. The transportation to the site is provided through a 1 km long connection road by turning left from the 12th km of Sinop-Erfelek main road. There are not any residential areas around the site in a distance less than 1,000 m. The nearest residential area is Eldevüz District on the 1,250 m southeast, Kümes and Uzungürgen Districts on the 1,500 m and 2,000 m south, and Yenimahalle District on the 1,750 m north. The distance of the site to the airport is more than 3 km.

In the design and estimation of the volume and area of the landfill site, embankment, isolation of the floor, volume of the daily and final cover are taken into account. These calculations are given in Table 6.1.

Figure 6.1. The photograph of the project site

Table 6.1. Calculation of Sinop (Meşedağı) sanitary landfill volume requirement

Year	Total MSW (Yearly)	Total MSW (Cumulative & Staged)	MSW Volume	Cover Soil Volume	Total Volume Requirement (Staged)	Total Volume Required (Cumulative)	Total Project Population
	ton/year	ton	m³	m³	m³	m³	capita
A		C	D	E***	F	G	H
A		B*	C/K1	DxK2/K3	D+E	F**	H
2000	**15 707**	**15 707**	**20 943**	**2 327**	**23 270**	**23 270**	**56 538**
2001	16 140	31 848	42 463	4 718	47 182	47 182	57 684
2002	16 586	48 433	64 578	7 175	71 753	71 753	58 853
2003	17 045	65 478	87 305	9 701	97 005	97 005	60 048
2004	17 518	82 997	110 662	12 296	122 958	122 958	61 269
2005	**18 006**	**101 003**	**134 670**	**14 963**	**149 633**	**149 633**	**62 516**
2006	18 508	119 511	159 348	17 705	177 053	177 053	63 789
2007	19 026	138 536	184 715	20 524	205 239	205 239	65 090
2008	19 559	158 096	210 794	23 422	234 216	234 216	66 419
2009	20 109	178 204	237 606	26 401	264 007	264 007	67 777
2010	**20 675**	**198 880**	**265 173**	**29 464**	**294 637**	**294 637**	**69 164**
2011	21 259	220 139	293 519	32 613	326 132	326 132	70 581
2012	21 861	242 000	322 666	35 852	358 518	358 518	72 028
2013	22 481	264 481	352 641	39 182	391 823	391 823	73 507
2014	23 120	287 601	383 468	42 608	426 076	426 076	75 018
2015	**23 779**	**23 779**	**31 706**	**3 523**	**35 228**	**461 304**	**76 561**
2016	24 458	48 238	64 317	7 146	71 463	497 539	78 138
2017	25 158	73 396	**97 861**	10 873	108 735	534 811	79 749
2018	25 880	99 276	132 368	14 708	147 076	573 152	81 395
2019	26 624	125 901	167 867	18 652	186 519	612 595	83 077
2020	**27 391**	**153 292**	**204 389**	**22 710**	**227 099**	**653 175**	**84 795**
2021	28 182	181 474	241 965	26 885	268 851	694 926	86 551
2022	28 998	210 472	280 629	31 181	311 810	737 886	88 345
2023	29 838	240 310	320 413	35 601	356 015	782 090	90 178
2024	30 705	271 015	361 353	40 150	401 503	827 579	92 050
2025	**31 599**	**302 614**	**403 485**	**44 832**	**448 316**	**874 392**	**93 964**
2026	32 520	335 134	446 845	49 649	496 494	922 570	95 919
2027	33 471	368 604	491 472	54 608	546 081	972 156	97 917
2028	34 450	403 055	537 406	59 712	597 118	1 023 194	99 959
2029	35 461	438 516	584 688	64 965	649 653	1 075 729	102 045
2030	**36 503**	**475 019**	**633 359**	**70 373**	**703 732**	**1 129 808**	**104 177**

K1 The unit volume weight of the MSW compressed at the site; 0.750 ton/m³

K2 Average thickness of the sub-cover soil, 0.20 m

K3 Average height of the MSW layer; 1.80 m

* Stage I: Year 2000-2014 ; Stage II : Year 2015-2030

** Accumulated value including both stages (Year 2000-2030)

*** The volume of the final cover soil is not included. The final cover soil volumes for Stage 1, Stage 2-I and Stage 2-II are 203 000 m³.

The landfill project includes 3 lots. The requirements for the volume and area of each lot are given in Table 6.2.

Table 6.2. Capacity and area of the lots

Lots	Volume (m^3)	Area (ha)	Capacity (year)	Period
Lot-1	426,076	5.45	15	2000-2015
Lot-2	546.081	6.03	13	2015-2028
Lot-3	157,651	2.64	3	2028-2030
Total	**1,129,808**	**14.62**	**30**	**2000-2030**

6.1.1. Geology, Hydrogeology and Hydrology

According to the geotechnical and hydrogeological evaluations in the project site, the soil layers in 2 m height section from ground-surface to the bottom consist of :

- 30 cm vegetable soil
- Clay with silt (yellow colored, high solid consistency)
- Hard Clay layer (brown color)

The permeability tests showed that the permeability of the brown hard clay layer is smaller than 1×10^{-8}, and yellow silty clay layer higher than 1×10^{-8}. The results of the tests also showed that by the compaction of these layers after excavation the permeability will be smaller than 1×10^{-8} as mentioned in Solid Waste Control Regulation. Also, the water table is not near to the surface.

There is not a tectonic movement in the area of landfill site. When the topographical properties are examined, the site is located on a boundary of a drainage area and there is not an erosion problem. The hydrological direction of the site is towards a river basin with an upstream from north.

6.1.2. Morphology

General slope of the area is about 6 - 8% . The site seems as a valley at the direction of north to northeast. On the west side of the site, Meşedağı with 102 m height and Nohutluk Hill with 122 m height are rising.

6.1.3. Climate

As it was given in Table 2.1. in Section 2. the average wind speed in the region is 6.5 m/sec with a direction of northwest. This will eliminate the odor problem over the project area. Because of the topographic properties, there will not be any negative effect caused by the rainfall. Stormwater will flow without any accumulation.

6.1.4. Landslide and Erosion

According to the interviews with the technical staff from the municipality, there is not any landslide and erosion in the project area. In addition, the area is covered with trees that prevents any erosion or landslide effect.

6.1.5. The Proprietary of the Area

The proprietary rights of the landfill site belong to Local Administration of Forests.

6.1.6. Protection Zones

The only protection zone around the region is the area around the Sarıkum Lake. This area is about 785 ha, and it is so far from the project area that the project has no effect.

6.1.7. Capacity

The project area has a landfill capacity to deposit 30-years solid wastes of the region.

6.1.8. Site Arrangements

The topographical map of the whole landfill site is given in Figure 6.2. As it can be seen from the map, the natural land has a slope from the direction of south to the northeast. The landfill site will be arranged as the bottom slope will be equal to 1/4.

The total area of the landfill site is about 16 hectars and the facility will serve for 30 years. It is not economic to design one lot for such a big area. Due to the topographical properties and the period of service. three lots have been planned. The MSW will be deposited in Lot-1 between 2000-2015, in Lot-2 between 2015-2028 and in Lot-3 between 2028-2030.

The principal method used for the landfilling in Sinop (Meşadağı) is the excavated cell/trench method. The excavated cell/trench method of landfilling is ideally suited to areas where an adequate depth of cover material is available at the site and where the water table is not near to the surface. Typically, solid wastes are placed in cells or trenches excavated in the soil. The soil excavated from the site is used for daily and final cover.

During the operation of the landfill site. 3 important procedures are have to be performed.

- The deposition of the wastes,
- Compaction of the wastes,
- The layering of sub-covers.

According to the planning studies, the total cell height of the daily waste deposited in the landfill was 2 m. First, the wastes was deposited with layers of 0.5 m height and then pressed. Secondly, the sub-covers of 0.20 m height soil was layered. Finally, daily cover was layered.

The location of the treatment plant will be at the northeast of the site which is the lowest elevation to drain the leachate by gravity. The buildings and other units that are planned to be located in the landfill site includes;

- Administration building,
- Garage and workshop,
- Guard house,
- Steelyard,
- Transformer building,
- Generator building,
- Wheel washing unit,
- Autopark,
- Daily cover soil storage area.

Roads, both within and outside of a landfill, are important in maintaining the smooth operation of a landfill. The road within the landfill should be designed so that dumping vehicles can move in and out easily (Bagchi, 1989).

The general layout of the lots, access roads, units and leachate treatment plant area within the landfill site is given in Figure 6.3.

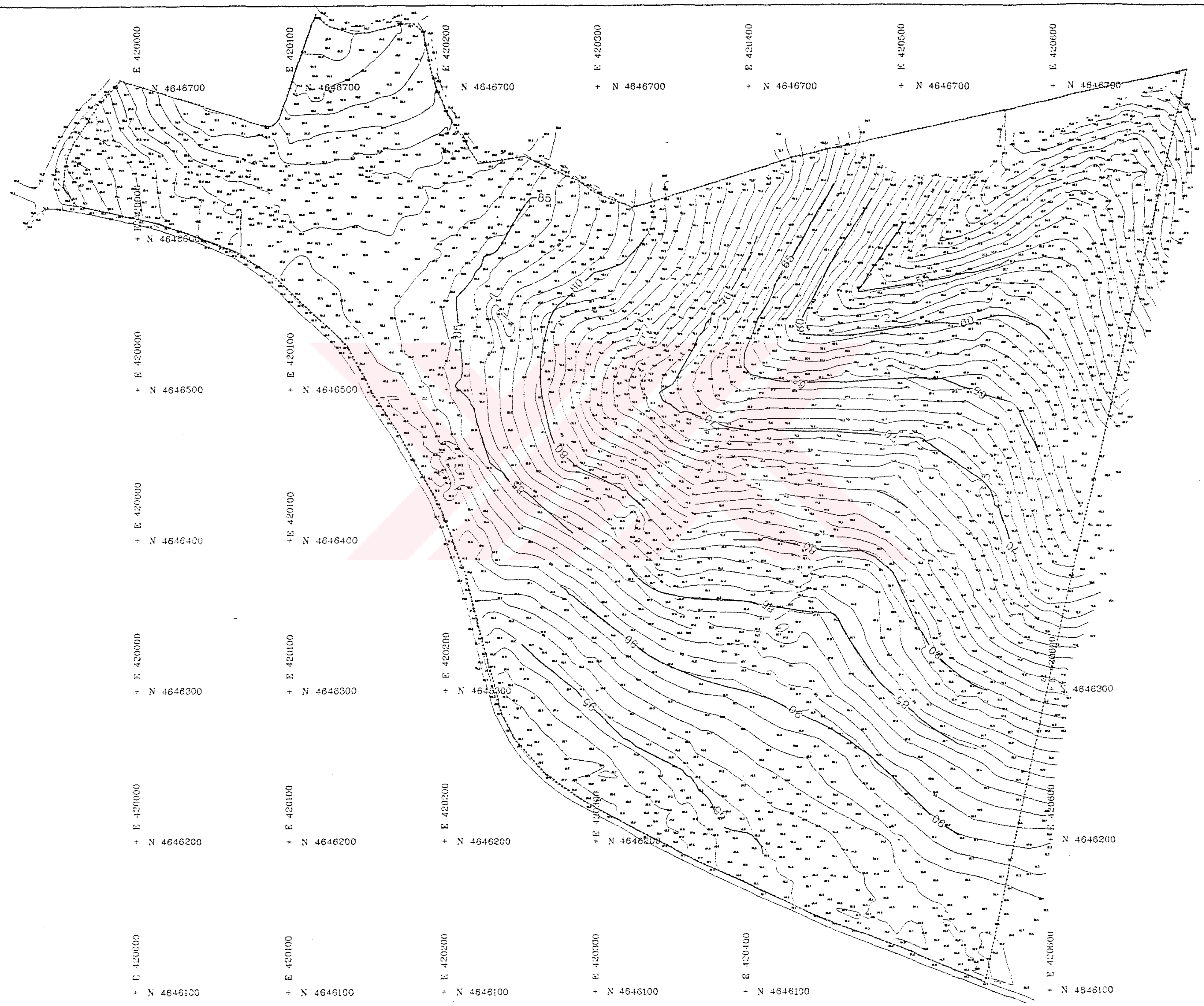


Figure 6.2. Topographical map of the project site

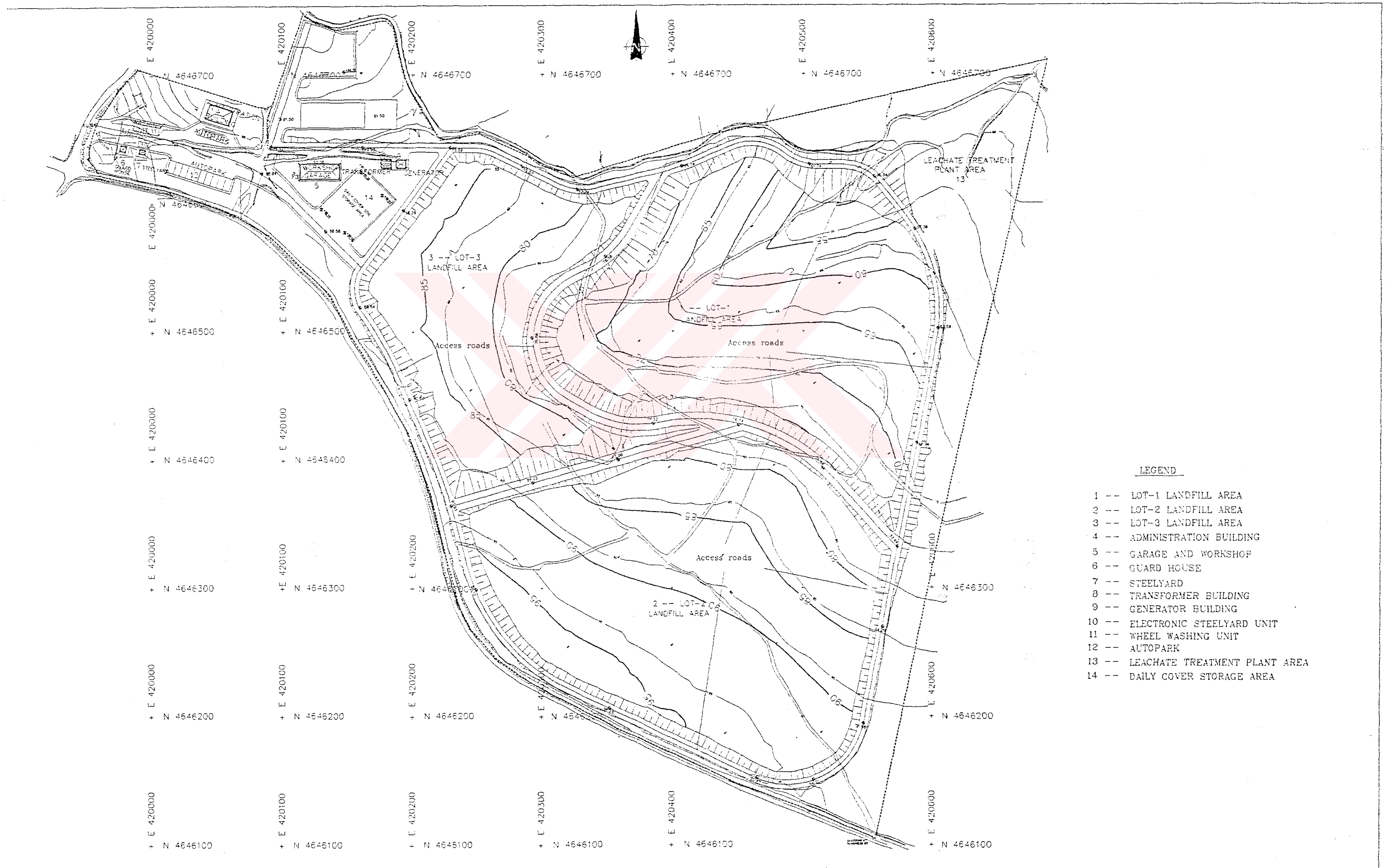


Figure 6.3. The general layout of the lots, access roads, units and leachate treatment plant area

6.2. Stability of Berms and Slopes

Both berms around a landfill and the waste slopes should be checked for stability to prevent any destruction. Many factors effect the stability; such as the height of the berm, climatic condition, effective angle of internal friction (ϕ'), effective cohesion (C), and unit weight of berm material. In addition, the effect of earthquakes on the structural stability of a berm constructed in earthquake-prone regions should be investigated (Bagchi, 1989).

Many methods have been developed for the stability analysis. Failure along a circular arc is assumed for most analysis. Geometry and forces in "method of slice" analysis are shown in Figure 6.4. Analysing the stability of a waste slope is somewhat difficult. A higher factor of safety (1.5-2) or lower values of ϕ^{I} and C should be used in arriving at a stable slope angle. Care should be taken to see that the entire slip circle is through the waste only and no part intercepts the berm (Bagchi, 1989). Maximum allowable slip-circle for the analysis of a waste slope is shown in Figure 6.5.

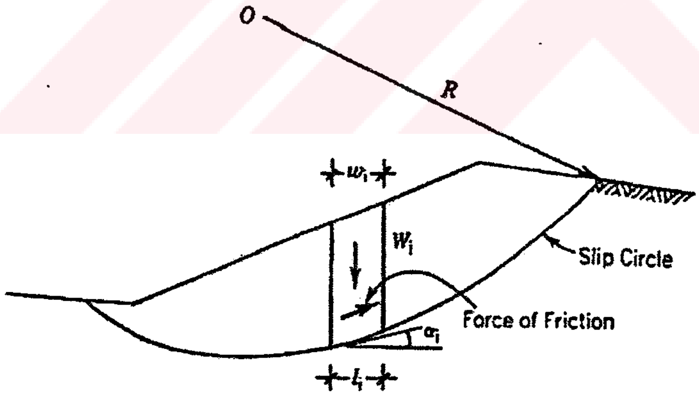


Figure 6.4. Geometry and forces in "method of slice" analysis (Bagchi, 1989)

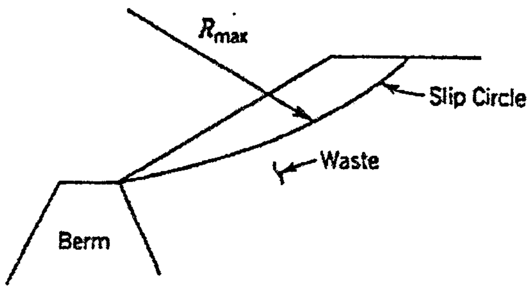


Figure 6.5. Maximum allowable slip-circle for analyzing a waste slope (Bagchi, 1989)

The "method of slice" analysis are performed by civil engineers for every lot in Sinop (Meşedağı) landfill. The study includes the analysis of the waste slope and berms at the left and right side of the wastes in every lot. The analysis for the sections A-A, B-B and C-C represents the stability situation for Lot-3, Lot-1 and Lot-2, respectively. The cross-sections of these lots determined in the stability analysis are shown in Figure 6.6. In the analysis, the stability of potential landslice surfaces was determined for different situations. The figures showing the results, include 10 landslide surfaces giving minimum security coefficients and these are shown in Figure 6.7a, b, c, d, e, and f.

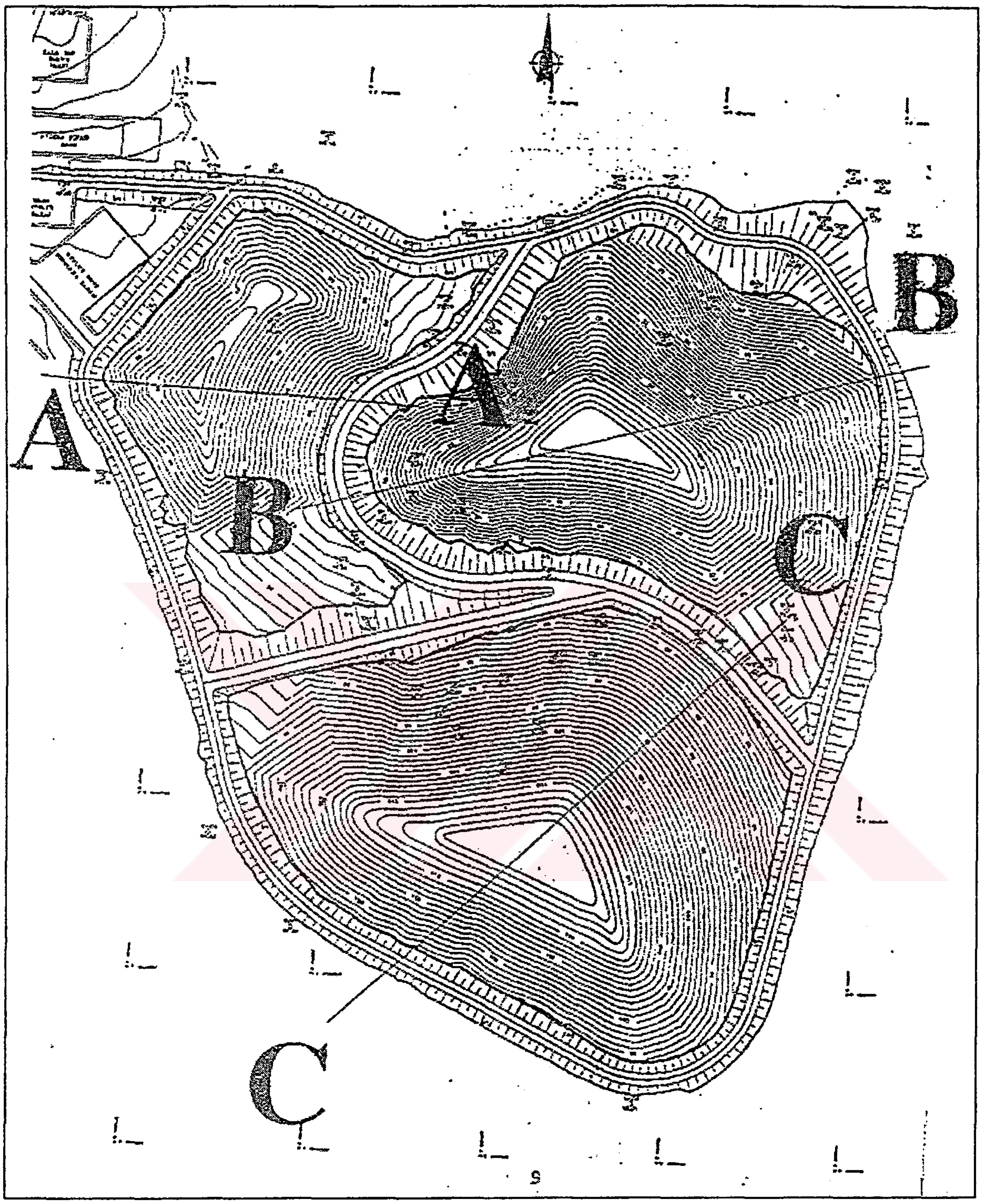


Figure 6.6. The cross-sections of the lots determined in the stability analysis

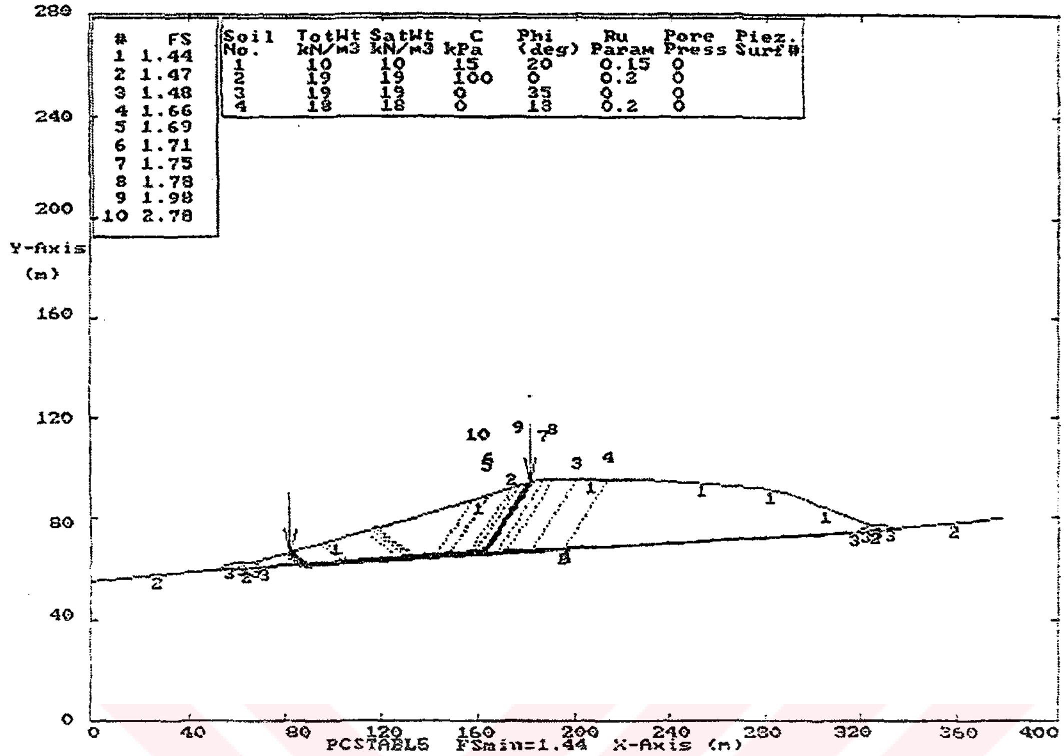


Figure 6.7a. 10 landslide surfaces giving minimum security coefficients in Lot-1 (right berm)

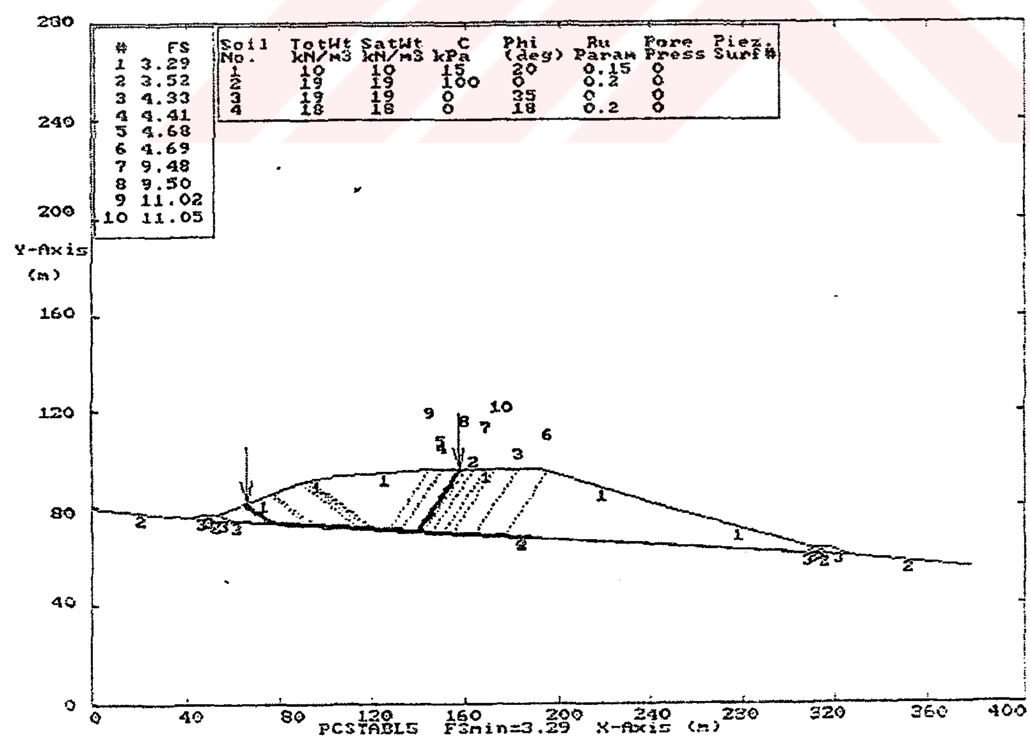


Figure 6.7b. 10 landslide surfaces giving minimum security coefficients in Lot-1 (left berm)

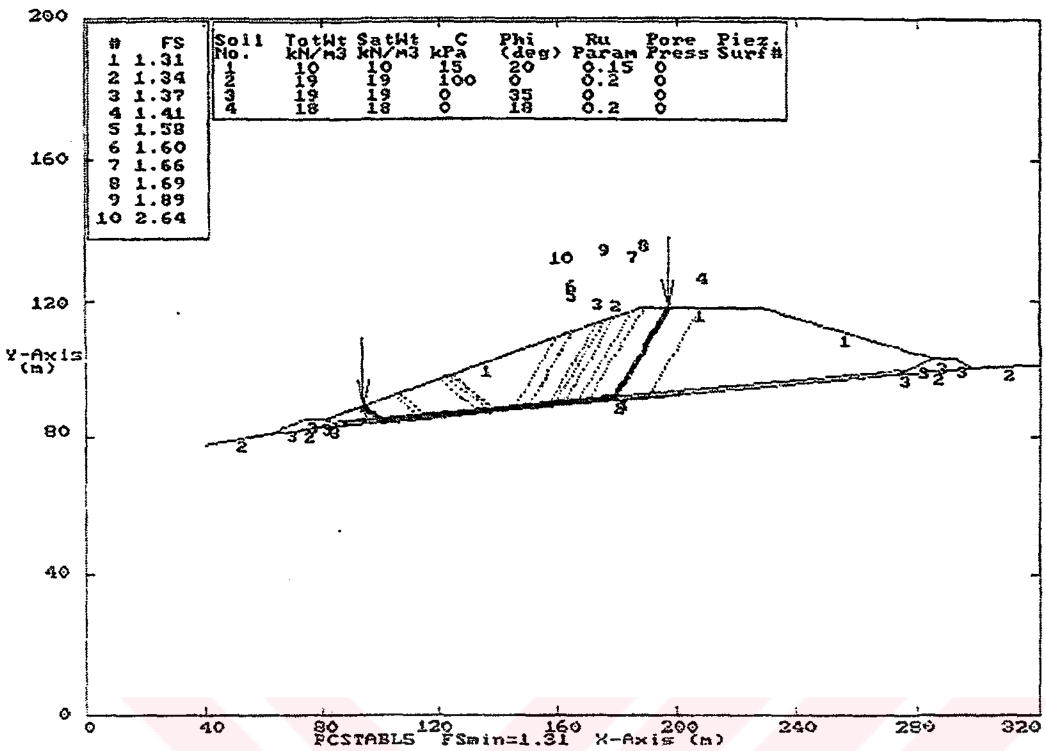


Figure 6.7c. 10 landslide surfaces giving minimum security coefficients in Lot-2 (right berm)

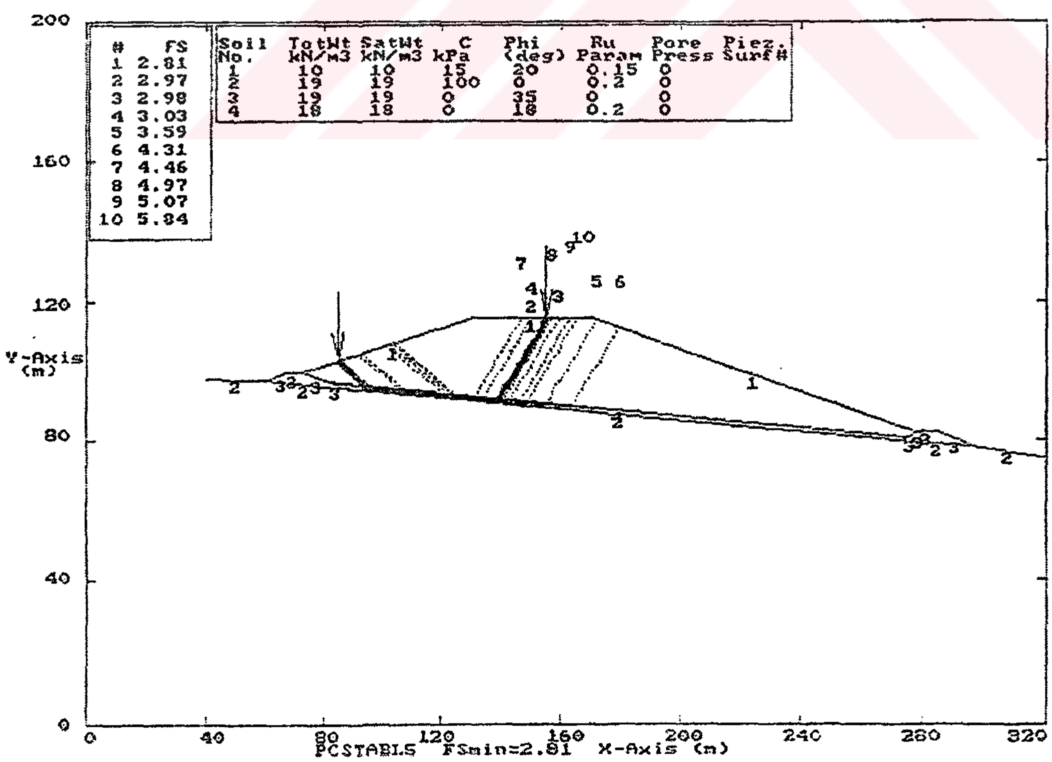


Figure 6.7d. 10 landslide surfaces giving minimum security coefficients in Lot-2 (left berm)

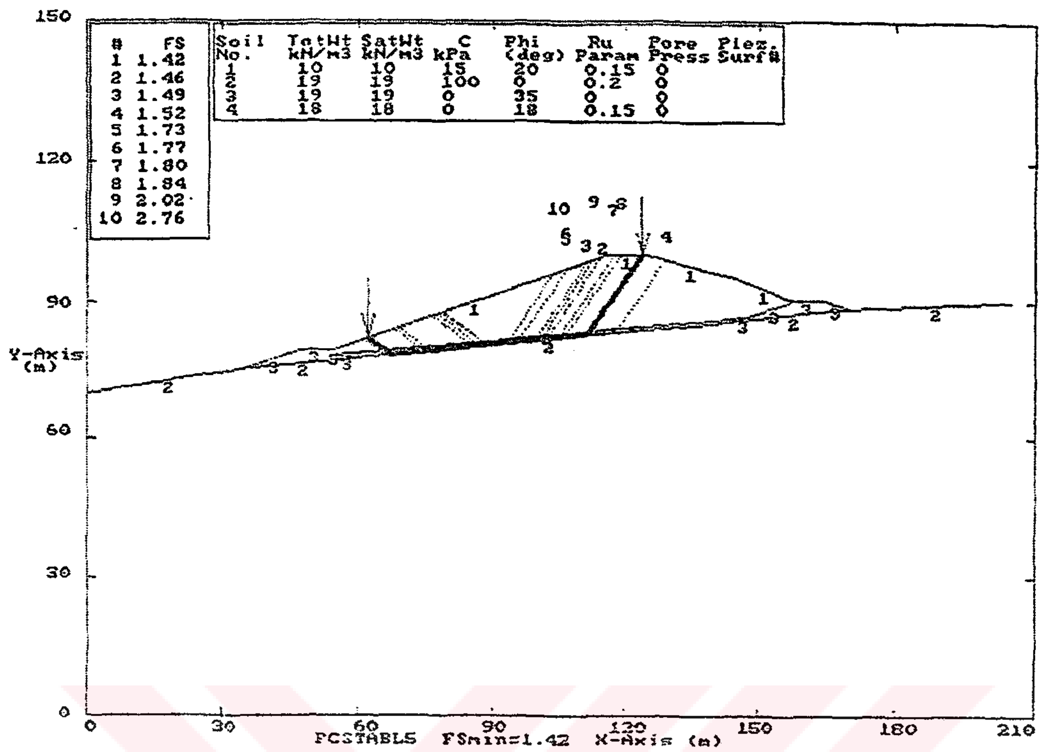


Figure 6.7e. 10 landslide surfaces giving minimum security coefficients in Lot-3 (right berm)

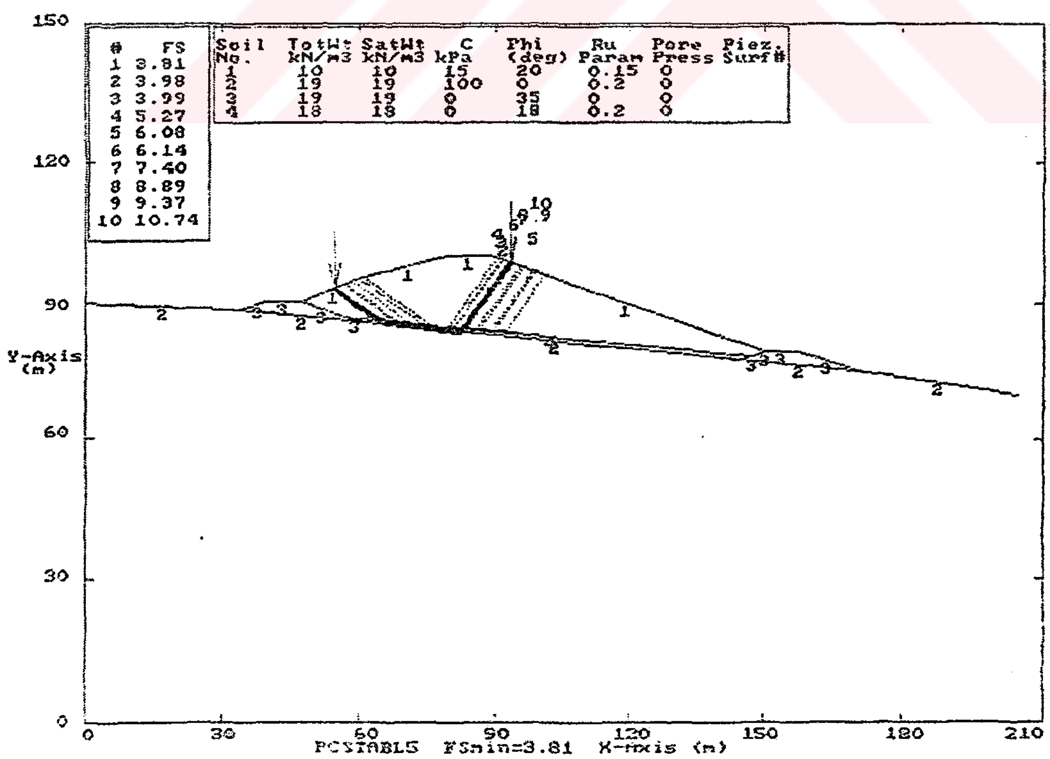


Figure 6.7f. 10 landslide surfaces giving minimum security coefficients in Lot-3 (left berm)

The parameters used in the stability analysis model are given in Table 6.3.

Table 6.3. The parameters used in stability analysis

	γ (kN/m³)	γd (kN/m³)	c (kPa)	ϕ	rU
MSW	10	10	15	20	0.15
Natural Ground (Hard Clay)	19	19	100	0	0.20
Berm	19	19	0	35	0
Seperating Surface	18	18	0	18	0.10

where;

γ : Unit volume weight. kN/m^3

γ_d : Water saturated unit volume weight. kN/m^3

c : Cohesion. kPa

ϕ : Internal friction angle

r_U : Pressure rate of water at pores

The layering of sand and geomembrane as a separating surface at the bottom of the waste is the most secure way used in landfills and in Sinop project this combination was used at the bottom of the site.

According to the studies performed at the project site, it was found out that the natural soil type is middle-hard clay. Thus, the parameters for the natural ground include the data as C=100 kPa and $\phi=0^{o}$.

The berms will be constructed with granular material as approximately 2 m height and the data for berms are chosen according to these properties.

The results of the stability analysis model are given in Table 6.4.

Table 6.4. The results of the stability analysis model

SECTIONS		SECURITY COEFFICIENT
Lot-3 ; Section A-A	Left Berm	3.81
	Right Berm	1.42
Lot-1 ; Section B-B	Left Berm	3.29
	Right Berm	1.44
Lot-2 ; Section C-C	Left Berm	2.81
	Right Berm	1.31

The minimum security coefficient was observed at the right berm of Section C-C as FS = 1.31, and the other data are over that value. Consequently, sufficient security will be provided as all the coefficients are over the value 1.

7. DESIGN OF LINER SYSTEMS

7.1. Liner Materials

Landfill liners are materials that are used to line the bottom area and below-grade sides of a landfill. The objective in the design of landfill liners is to minimize the infiltration of leachate into the subsurface soils below the landfill thus eliminating the potential for groundwater contamination.

Liners usually consist of a layer of compacted clay or geosynthetic material designed to prevent migration of landfill leachate and landfill gases. The usage of clay as a liner material has been the favored method of reducing or eliminating the seepage of leachate from landfills (Tchobanoglous et al., 1993).

Typical liner materials are :

Clay; is the most important component of soil liners because the clay fraction of the soil ensures low hydraulic conductivity. Clay is favored for its ability to adsorb and retain many of chemical constituents found in leachate and for its resistance to the flow of leachate. However, the use of combination composite geomembrane and clay liners is gained in popularity, especially because of resistance afforded by both leachate and landfill gases. The clay layer and geomembrane serve as a composite barrier to the movement of leachate and landfill gases (Tchobanoglous et al.. 1993).

Geosynthetic; is general term that includes geotextiles, geomembranes, geonets, and geogrids. The selection of the geosynthetic appropriate for a specific circumstance depends on its required function. Example of specific functions include (U.S. EPA, 1993):

- Filtration ; to retain soil while allowing the passage of water
- Transmission ; to enhance lateral drainage.
- Isolation ; to isolate two constituents from each other.
- Barrier ; to decrease the transmission of water.

Geomembranes are relatively thin sheets of flexible thermoplastic or thermoset polymeric materials that are manufactured and prefabricated at a factory and transported to the site. Because of their inherent impermeability, use of geomembranes in landfill unit construction has increased. The design of the side slope, specifically the friction between natural soils and geosynthetics, is critical and requires careful review (U.S. EPA. 1993)

Geonets may be substituted for the granular layers of the LCRs on the bottom and sidewalls of the landfill cells. Geonets require less space than perforated pipe or gravel and also promote rapid transmission of liquids. They do, however, require geotextile filters above them and can experience problems with creep and intrusion. Long-term operating and performance experience of geonets is limited because the material and its application are relatively new (U.S. EPA. 1993).

Geotextile filter fabrics are often used to minimize the intermixing of the soil and sand or gravel layer. The open spaces in the fabric allow liquid flow while simultaneously preventing upstream fine particles from fouling the drain. Geotextiles save vertical space, are easy to install, and have the additional advantage of remaining stationary under load. Geotextiles also can be used as cushioning materials above geomembranes. Because geotextile filters are susceptible to biological clogging, their use in areas inundated by leachate (e.g., sumps, around leachate collection pipes, and trenches) should be avoided (U.S. EPA, 1993).

The geonet and geotextile together enables leachate flow to the leachate collection system. Because of the potential for the geotextile filter cloth to clog, many designers favor the use of a sand or gravel as the drainage layer. Composite liners are identified as the primary and secondary liners. The primary composite liner is used for the collection of leachate; secondary liner serves as a leak-detection system and a backup for the primary composite liners (U.S. EPA, 1993).

Geogrids are used for slope stability and geomats for prevention of erosion of slopes such as landfill caps (U.S. EPA, 1993).

The sand and gravel layer; serve as a collection and drainage layer any leachate that may be generated within the landfill (U.S. EPA, 1993).

7.2. Factors Affecting the Selection of Liner Systems

The selection of liner system mainly depends on the waste type and landfill operation. The liner material must be compatible with leachate properties. In other words, the leachate generated from the waste must not degrade the liner material. Additionally, the selection of liner system to achieve the performance objectives determined by the risk assessment will be influenced by the availability of materials, either on-site or locally. An assessment of costs will generally indicate that a liner system should only incorporate natural materials, which are available within a reasonable distance of the site. Consequently, there will be regional variation in the design of a liner system based on local geology (Bagchi, 1989).

Liner systems should, in addition to the property of low permeability, be robust, durable, and resistant to chemical attract, puncture and rupture (Bagchi, 1989).

Robustness, durability and puncture resistance may be provided by;

- The inherent strength of liner components themselves,
- The combination of two or more components acting synergistically,
- Physical thickness,
- Protective layers,
- Liner types.

A landfill liner system may comprise a combination of barriers and fluid collection layers, plus mineral or synthetic components fulfilling a separation or protection function.

According to the Solid Waste Control Regulation, landfill basement should be non-permeable. For this purpose, landfill base should be compacted with a clay layer having a minimum thickness of 60 cm. Hydraulic conductivity value of the compacted base should be maximum 1×10^{-6} cm/sec. However, where non-weathered rocky bases are present, hydraulic conductivity value can be 1×10^{-5} cm/sec. Over the compacted clay layer, a high-density geosynthetic liner and a lateral drainage layer should be constructed (Clause 26, Item 2).

In the revision to the solid waste control regulation, it was stated that, landfill basement should be a minimum of 1 m above the groundwater table level. (Clause 26, Item 1) On the other hand, a geosynthetic liner usage of HDPE with a density of 941-965 kg/m^3 is advised. (Clause 26, Item 2) Additionally, the minimum drainage pipe diameter and its slope should be 100 mm and 1%, respectively. Finally, lateral drainage layers should be composed of high permeability gravel or sand and the thickness should be 30 cm. (Clause 26, Item 3)

7.3. Selection of Liner Systems

7.3.1. Sub Base Liner System

The main criteria in the selection of the sub base liners is "Solid Waste Control Regulation". The cross-section of the sub base liners selected for Sinop (Meşedağı) Sanitary Landfill Project is given in Figure 7.1.

Starting from the basement to the top section, the properties of the layers are described as follows:

1) Natural Soil Basement Layer

Natural soil basement layer is composed of hard clay. According to the results of permeability tests, the hydraulic conductivity of this layer is smaller than 1×10^{-8} m/s.

2) Compacted Clay Layer

Depending on the Turkish Solid Waste Regulations, municipal waste lots in landfills should have a compacted clay layer having two layers with a depth of 30 cm reaching a total depth of 60 cm and reaching a maximum hydraulic conductivity of 1×10^{-8} m/s.

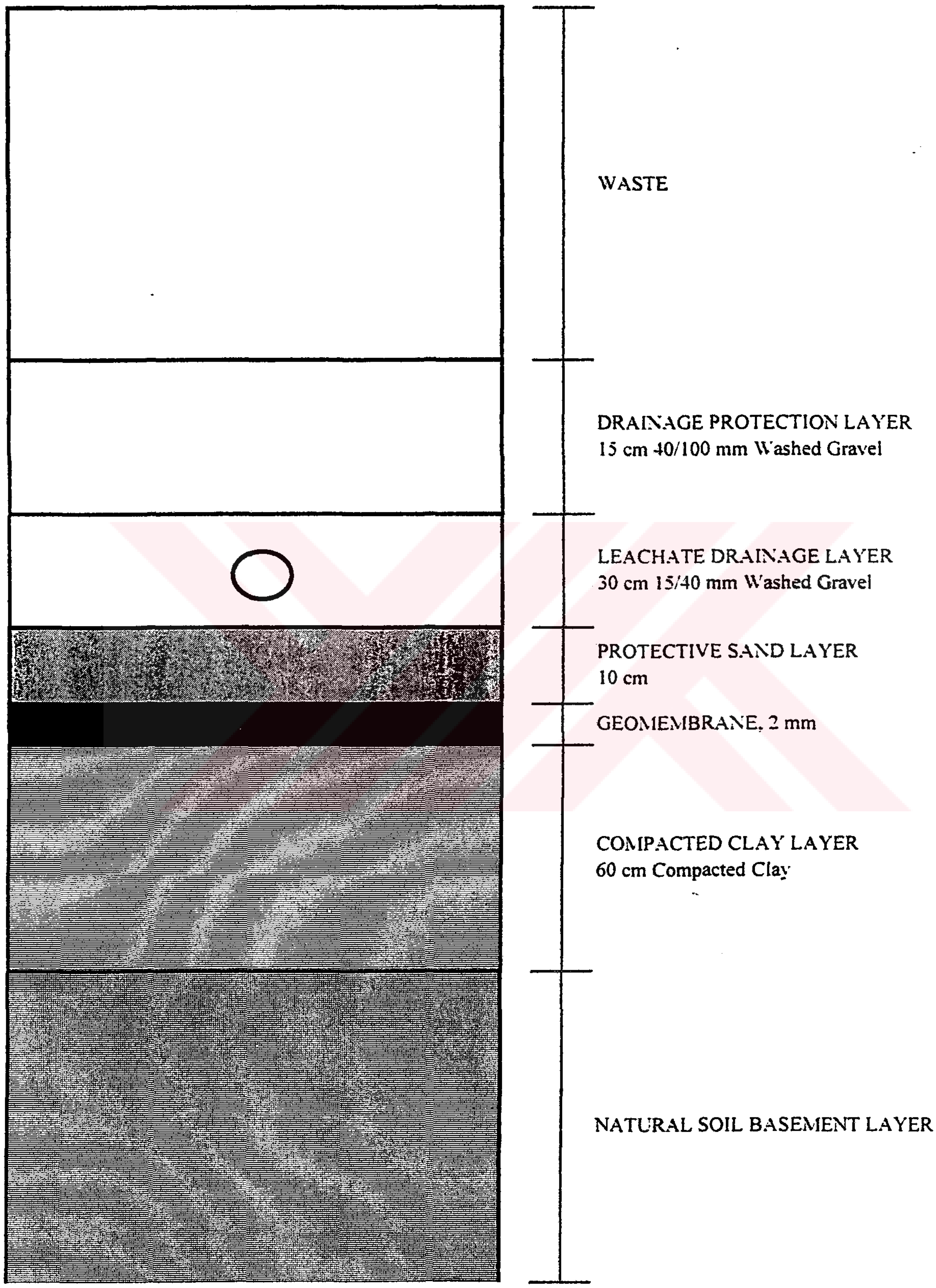


Figure 7.1. The cross-sectional view of sub base liners

3) Geomembrane Liner

To have a composite liner and a good protection for possible leakages from the bottom of the landfill, a geosynthetic liner should be layered above the compacted clay layers. Geomembrane thickness should be minimum 2 mm according to Turkish Solid Waste Regulation. Additionally, density of the liner should be between 941 and 965 kg/m^3.

Geomembranes are manufactured from the first quality virgin, high molecular weight resin for the purpose of hydraulic containment. Geomembranes should be free of plasticizers and other leachable additives. Each manufactured geomembrane roll should be electronically monitored for pinholes.

Geomembrane liners should be placed with the assistance of the manufacturer not to have wrinkles, punctures and defects. The geomembrane liners are generally welded using either an extrusion or a fusion (hot wedge) process. Welded seams should be visually inspected. Additionally, the welded seams should be tested both on site and in laboratories.

4) Protective Sand Layer

Sand layer with a depth of 10 cm has been layered in order to protect the geomembrane from the possible threats that the leachate drainage layer above could have. This layer has been formed by using concrete sand.

5) Leachate Drainage Layer

A drainage layer composed of gravel having diameters between 15 and 40 mm has been layered to drain the leachate out of the site. The thickness of this layer is 30 cm which enables leachate to quickly reach to the leachate drainage pipes. Perforated HDPE pipes have been placed in the drainage layer to create a collection system. Mimimum 100 mm pipe diameters have been chosen depending on the calculations in order to drain all the possible leachate amounts easily and quickly.

6) Drainage Protective Gravel Layer

Over the drainage layer another gravel layer is layered to act as a vertical percolation layer and to protect the drainage pipes. Depending on the Turkish Solid Waste Regulation, this layer should have a depth of 15 cm and a maximum hydraulic conductivity of 1×10^{-2} cm/sec.

7.3.2. Final Cap

The final cap should be constructed in order to minimize the amount of water entering the landfill. Depending on the Solid Waste Regulation, cross-sectional view of final cap in Sinop (Meşedağı) sanitary landfill is given in Figure 7.2.

The properties of the layers are described as follows:

1) Stabilizing Barrier Soil Layer

Stabilizing barrier soil should be layered over the solid waste and the side walls. Soils that will be used in this layer should have a low permeability. Thickness of this layer is 30 cm.

2) Gas Drainage Layer

Gas drainage layer is composed of gravel having diameters between 15 and 40 mm. This layer will enable gas to reach the gas collection wells horizontally. Thickness of this layer is 30 cm.

3) Barrier Clay Layer

Barrier clay layer includes two layers of clay with a depth of 30 cm reaching a total depth of 60 cm and reaching a maximum hydraulic conductivity of 1×10^{-6} cm/sec.

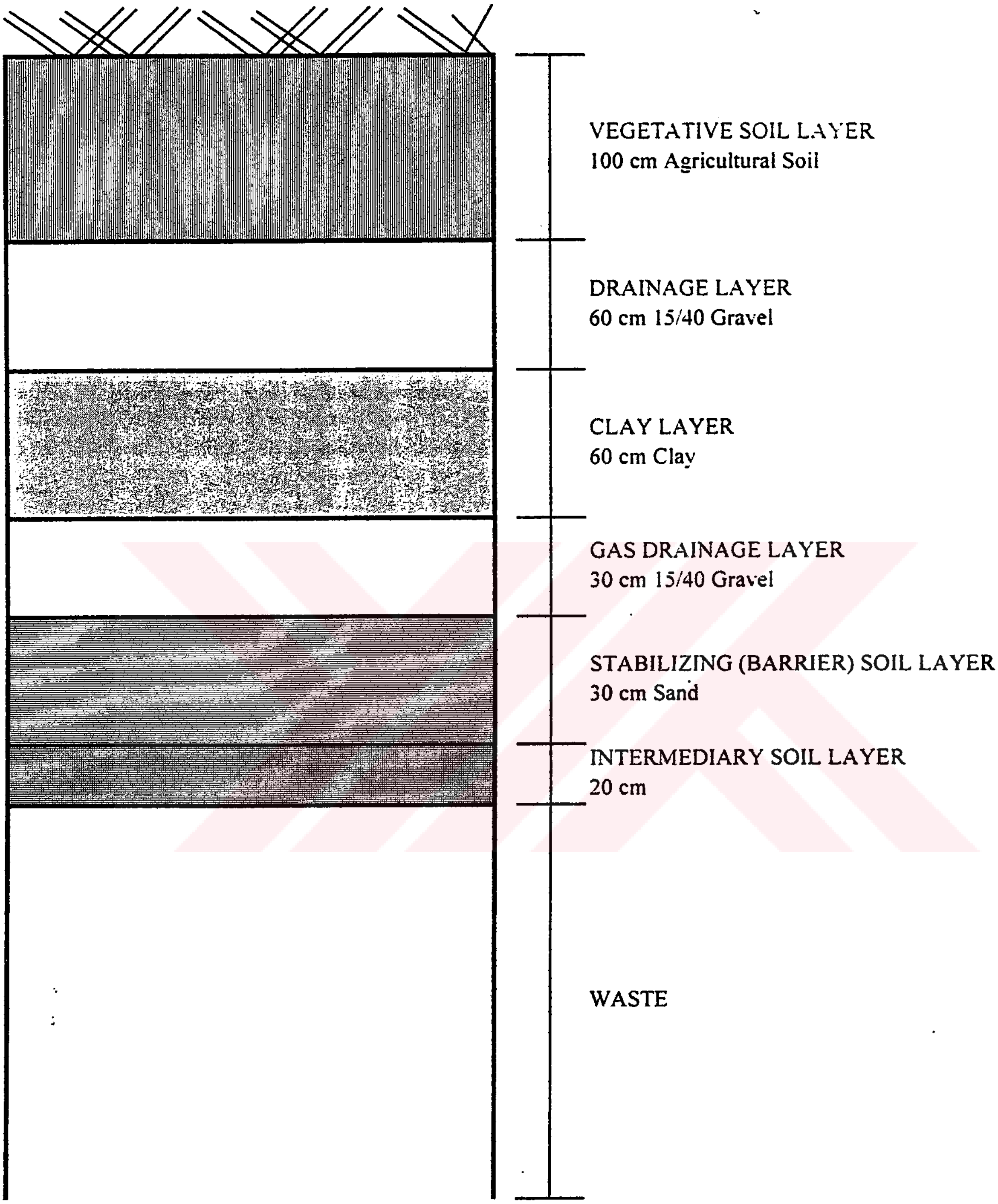


Figure 7.2. The cross-sectional view of final cap

4) Drainage Layer

This layer is composed of gravel having diameters between 15 and 40 mm. It enables the water percolated through the agricultural soil layer to drain. Consequently, the amount of water reaching to barrier clay layer is minimized.

5) Vegetative Agricultural Soil Layer

Over the drainage layer, minimum 100 cm thick agricultural soil should be layered, which consists of agricultural soil in order to enable enough vegetative growth. The slope of this layer should be minimum 3% to enable runoff.

8. DESIGN OF LEACHATE COLLECTION SYSTEM

The production of leachate from municipal sanitary landfills is an important environmental concern. Many factors like annual precipitation, runoff, infiltration, evaporation, transpiration, freezing, waste composition, waste density, initial moisture content and depth of the landfill affect the amount of leachate generated.

8.1. Leachate Generation

The numerical models selected to evaluate the potential generation of leachate from the landfill are the HELP (Hydraulic Evaluation of Landfill Performance) and Water Balance Model. HELP model which was developed by EPA is a mass balance model capable of estimating leachate quantities through the different components of a landfill (Schroeder et al., 1997). On the other hand, the *Water Balance Model* is an MS Excel implementation of the Thorntwaite and Benfratello formula (Canziani et al., 1989).

8.1.1. HELP (Hydraulic Evaluation of Landfill Performance) Model

The Hydraulic Evaluation of Landfill Performance (HELP) computer program is a quasi two-dimensional, hydrologic model of water movement across, into, through and out of landfills. The HELP model requires three general types of input data for each model profile:

(1) Weather data (precipitation, solar radiation, temperature, evapotranspiration parameters), (2) Soil properties (porosity, field capacity, wilting point, and hydraulic conductivity), (3) Design information (liners, leachate and runoff collection systems, surface slope).

The HELP model (Versions 1, 2 and 3) was developed by the U.S. Army Engineer Waterways Experiment Station (WES), for the U.S. Environmental Protection Agency (EPA). The model was adapted from the HSSWDS (Hydrologic Simulation Model for Estimating Percolation at Solid Waste Disposal Sites) model of the U.S. EPA. The HELP model uses many process descriptions that were previously developed, reported in the literature, and used in other hydrologic models (Schroeder et al., 1997).

The HELP model uses solution techniques that account for surface storage, snowmelt, runoff, infiltration, vegetative growth, evapotranspiration, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. The model also accounts for the change in slope for different parts of the landfill profile (Schroeder et al., 1997) .

Results of the model are expressed as daily, monthly, annual and long-term average water balances and can be used to compare the leachate production potential of alternative designs, to select and size appropriate drainage and collection systems, and to size leachate treatment facilities. The HELP model is applicable to open, partially closed, and fully closed sites.

8.1.2. Water Balance Model

The analysis of the water balance of landfills can be carried out further to predict leachate production in completed landfills. A schematic representation of a closed sanitary landfill with leachate drainage system and its general hydrological balance components is shown in Figure 8.1.

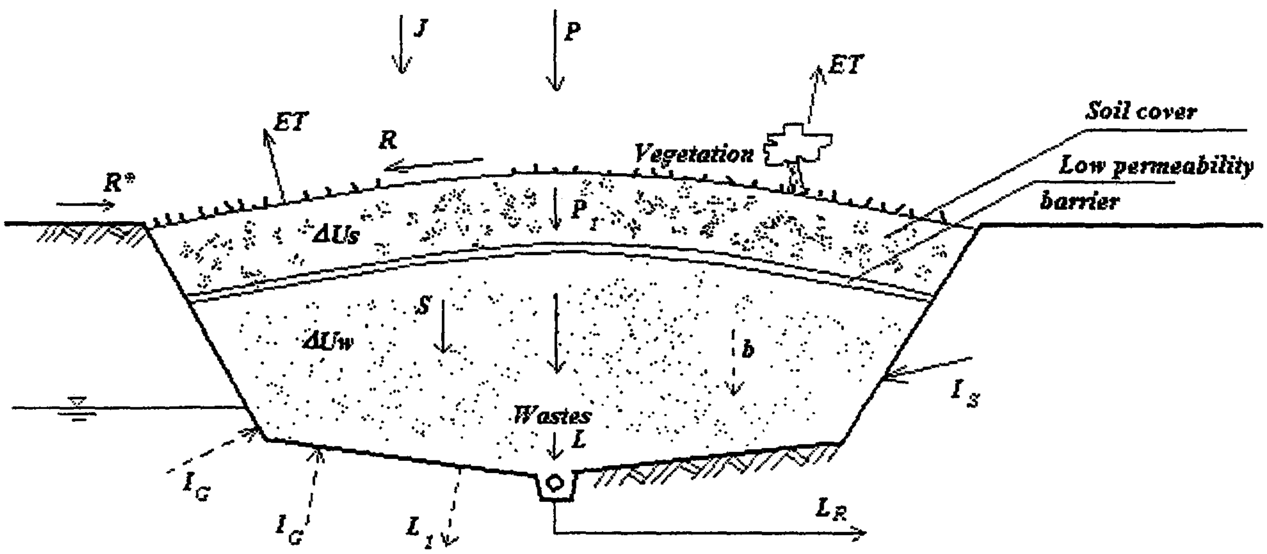


Figure 8.1. Schematic of the general hydrological balance in a completed sanitary landfill with leachate drainage system (Thornthwaite et al., 1955)

P : Precipitation

J : Irrrigation or leachate recirculation

R : Surface runoff

R* : Runoff from external areas

ET : Actual evapotranspiration

Us : Water content in soil

Uw : Water content in wastes

S : Water added by sludge disposal

b : Water production (if>0) or consumption (if<0) caused by the biological degradation of organic matter

I_S, I_G : Water from natural aquifers

L_1 : Infiltration into aquifers

L_R : Leachate collected by drains

L : Total leachate production

$$P_i = P + J + R^* - R - ET \pm \Delta Us \quad (8.1)$$

$$L = P1 \pm \Delta Uw + b \quad (8.2)$$

By synthesizing the above cited terms, the water balance model can be expressed as:

$$P - E \pm \Delta Uw - R = L_R \tag{8.3}$$

8.2. Development of HELP Model, Input Data and Results

Data used in the simulation of the Sinop Sanitary Landfill in the HELP model platform and model development steps are described. The HELP model requires general climate data for computing potential evapotranspiration, daily climatologic data, soil characteristics, and design specifications to perform the water budget analysis.

8.2.1. Weather Data

The required general climate data include plant growing season, average annual wind speed, average quarterly relative humidities, normal mean monthly temperatures, maximum leaf area index, evaporative zone depth and latitude. Moreover, daily weather data requirements include precipitation, mean temperature and total global solar radiation.

The HELP model runs are performed using the temperature and precipitation data given in Table 2.1 and other weather data used during the model runs are as stated in Table 8.1.

Table 8.1. Additional weather data required by the HELP model (Schroeder et al., 1997)

Dates starting and ending the growing season (1st of January is 1)	50 / 310 day/day
Normal average annual wind speed	23.4 km/hr
Normal average quarterly relative humidity	
First quarterly relative humidity (January – March):	74,67 %
Second quarterly relative humidity (April – June) :	79,33 %
Third quarterly relative humidity (July – September) :	76,67 %
Fourth quarterly relative humidity (September – December):	74,67 %
Latitude of Sinop	41.40° N
Solar Radiation Data is synthetically generated for landfill latitude	41.40° N
Evaporative Zone Depth (open lot & during operation)	1
Evaporative Zone Depth (after closure)	20
Leaf Area Index (open lot & during operation)	0
Leaf Area Index (after closure)	3

8.2.2. Soil Data

The soil data required by the HELP model include porosity, field capacity, wilting point, saturated hydraulic conductivity, initial moisture storage, and Soil Conservation Service (SCS) runoff curve number. The porosity, field capacity, wilting point and saturated hydraulic conductivity are used to estimate the soil water evaporation coefficient and soil moisture retention parameters.

Default values provided by the HELP model for comparable soil types were used for the soil parameters.

8.2.3. Design Data

Lot-1, Lot-2 and Lot-3 of the Sinop Sanitary Landfill is simulated using the HELP model. Design specifications used in the model runs include the slope, maximum drainage distance for lateral drainage layers, layer thicknesses, layer description, area of the lots, surface characteristics, geomembrane characteristics, leachate recirculation procedure, and subsurface inflows. The design data used in HELP model platform to simulate Sinop Sanitary Landfill, are stated below:

<u>8.2.3.1. General Information of Lot-1, Lot-2 and Lot-3 :</u> General Information on Lot-1, Lot-2 and Lot-3 are given in Tables 8.2, 8.3 and 8.4. respectively. During simulation of Sinop Sanitary Landfill in HELP platform, landfill lots were assumed to be homogeneous spatially.

Table 8.2. General information on Lot-1

Area of Lot-1 (area projected on the horizontal plane)	5.45 hectares
Volume of Lot-1	426 076 m^3
Active Period	15 years
Average Total Height of solid waste disposed to Lot-1	800 cm
Dumped and compacted solid waste height increase every year	45 cm
Percent of area where runoff is possible (area allowing runoff)	100 %
Initial snow or rain water on surface	0.0 mm

Table 8.3. General information on Lot-2

Area of Lot-2 (area projected on the horizontal plane)	6.03 hectares
Volume of Lot-2	546 081 m^3
Active Period	13 years
Average Total Height of solid waste disposed to Lot-2	900 cm
Dumped and compacted solid waste height increase every year	65 cm
Percent of area where runoff is possible (area allowing runoff)	100 %
Initial snow or rain water on surface	0.0 mm

Table 8.4. General information on Lot-3

Area of Lot-3 (area projected on the horizontal plane)	2.64 hectares
Volume of Lot-3	157 651 m^3
Active Period	3 years
Average Total Height of solid waste disposed to Lot-3	600 cm
Dumped and compacted solid waste height increase every year	200 cm
Percent of area where runoff is possible (area allowing runoff)	100 %
Initial snow or rain water on surface	0.0 mm

8.2.3.2. Hydrological Properties of the Sub Base Layers of Lot-1, Lot-2 and Lot-3 : The basement layers (landfill layers below the solid waste layer) of municipal waste lots of Sinop Sanitary Landfill are modeled in HELP platform by using the data given in Table 8.5. During the modeling processes, initial moisture content of the layers and snow water are computed as nearly steady-state values by HELP. Furthermore, geomembrane placement quality is assumed to be good. On the other hand, geomembrane layers are assumed to contain no pinholes and no installation defects.

In Table 8.5, hydrological properties of the basement layers of Lot-1, Lot-2 and Lot-3 are given. The data given in the table are directly used in the model to simulate the municipal waste lots. Layer 1 represents the upper layer in the basement layers section.

Table 8.5. Hydrological properties of the basement layers of Lot-1, Lot-2 and Lot-3

Layer Number	Layer Name	Properties of Layers
1	Drainage Protection Layer	Type 1 – Vertical Percolation Layer 40 / 100 mm Washed Gravel 15 cm Porosity = 0.3970 vol/vol[1] Field Capacity = 0.0320 vol/vol[1] Wilting Point = 0.0130 vol/vol[1] Initial Soil Water Content = 0.0742 vol/vol[2] Effective Saturated Hydraulic Conductivity = 0.3 cm/sec[1]
2	Leachate Drainage Layer	Type 2 – Lateral Drainage Layer 15/40 mm Washed Gravel 30 cm Porosity = 0.3200 vol/vol[1] Field Capacity = 0.0500 vol/vol[1] Wilting Point = 0.0200 vol/vol[1] Initial Soil Water Content = 0.1049 vol/vol[2] Effective Saturated Hydraulic Conductivity = 0.2 cm/sec[1] **Lot-1** Drainage Length = 1526 meters[3] Slope = 6 %[3] **Lot-2** Drainage Length = 1804 meters[3] Slope = 4 %[3] **Lot-3** Drainage Length = 745 meters[3] Slope = 3 %[3]
3	Geomembrane Layer	Type 4 – Flexible Membrane Liner Geomembrane 2 mm Porosity = 0 vol/vol[1] Field Capacity = 0 vol/vol[1] Wilting Point = 0 vol/vol[1] Initial Soil Water Content = 0 vol/vol[2] Effective Saturated Hydraulic Conductivity = 2×10^{-13} cm/sec[4]
4	Compacted Clay Layer	Type 1 – Vertical Percolation Layer Compacted Clay 60 cm Porosity = 0.4510 vol/vol[1] Field Capacity = 0.4190 vol/vol[1] Wilting Point = 0.3320 vol/vol[1] Initial Soil Water Content = 0.4190 vol/vol[2] Effective Saturated Hydraulic Conductivity = 0.68×10^{-6} cm/sec[5]
5	Natural Soil Basement Layer	Type 3 – Barrier Soil Liner 200 cm Hard Silty Clay Porosity = 0.4520 vol/vol[1] Field Capacity = 0.4110 vol/vol[1] Wilting Point = 0.3110 vol/vol[1] Initial Soil Water Content = 0.4520 vol/vol[2] Effective Saturated Hydraulic Conductivity = 0.1×10^{-6} cm/sec[1]

[1]Values suggested by the HELP model manual (Schroeder et al., 1997) . These values of porosity, field capacity, wilting point and saturated hydraulic conductivity are used since no laboratory tests were performed on these soils. Values suggested by the HELP manual for these types of layers are obtained from extensive studies and tests on various types of landfill layers in U.S.A.

[2]Moisture values obtained at the end of the previous one year model runs.

[3] Values calculated based on the lengths of the drainage pipelines planned in previous secitons.

[4]HELP model default values.

[5]Values chosen based upon the Turkish Solid Waste Regulations (Turkish Solid Waste Regulation, 1991).

8.2.3.3. Hydrological Properties of the Solid Waste and Intermediary Soil Layers of the Modeled Lots : To account for the changes occurring during the development stage of the landfill (active solid waste disposal), the model considers the landfill to consist of lifts that are constructed progressively with time. The HELP model does not contain a component that considers the continued loading of waste for an active cell and it recommends modeling each year separately by adding on the additional waste loadings for each year. Each time step represents the period of time after which a new lift or cell is finished. At the end of each time step (one year), the new lift or cell is introduced into the HELP model system. In this way, the development of Sinop Sanitary Landfill is simulated (Figure 8.2). Additionally, each year's initial moisture values are based upon the previous year's final moisture value.

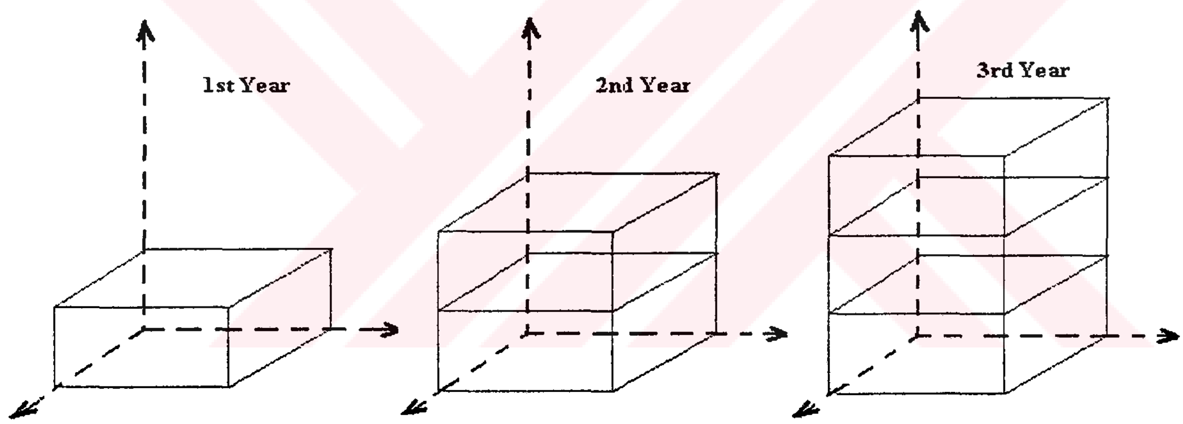


Figure 8.2. Time dependent development of the solid waste lifts of the modeled landfill (Schroeder et al., 1997)

A solid waste lift that is introduced to the HELP modelling platform can be represented as a rectangular prism given in Figure 8.3. It should be noted that the area of the top layer should be equal to the area of the simulated lot and the thickness of the solid waste layer should be equal to the thickness of the solid waste layer introduced to the landfill annually.

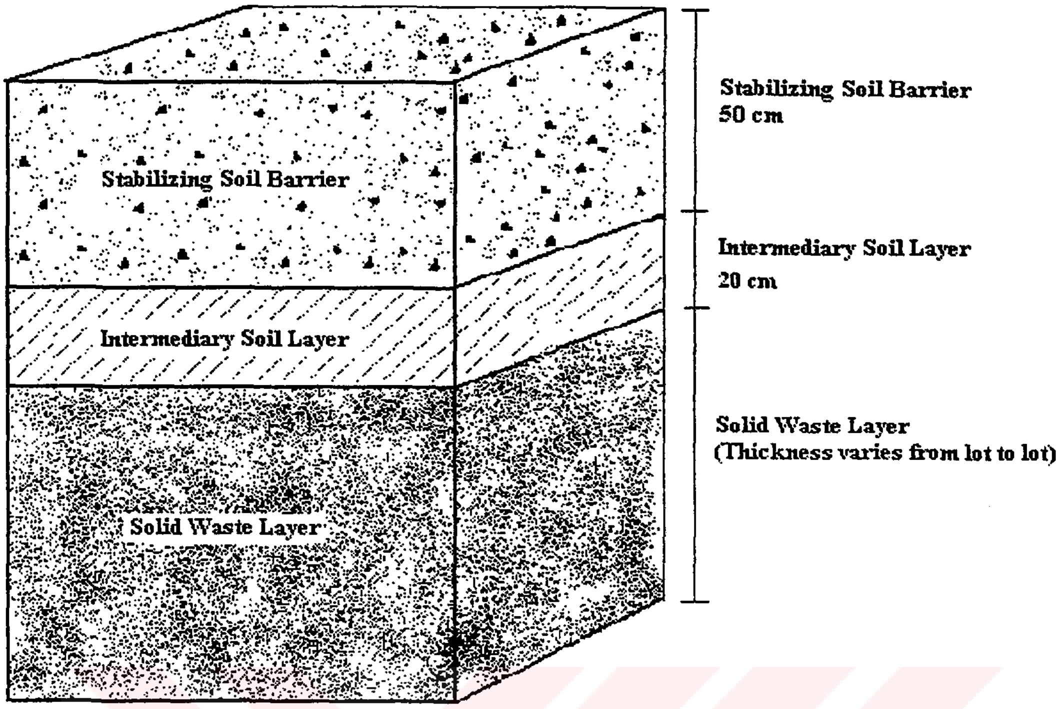


Figure 8.3. Representation of the solid waste lifts introduced into the HELP model system at the end of each disposal time step (Schroeder et al., 1997)

During modelling, thickness of the intermediary soil layer was kept constant at 20 cm for all the lots. On the other hand, intermediary soil layer term was used instead of daily soil cover term since covering the solid waste with a soil layer process was not performed daily on site. Thus, it was assumed that the solid waste layer is covered at the end of each year completely with a non-compacted soil layer having a thickness of 20 cm. Moreover, as the simulated lot is closed to solid waste disposal, the lot is covered with an additional stabilizing soil barrier. Figure 8.4 represents the final solid waste lift that is introduced into the HELP model system when the related lot is closed to solid waste disposal.

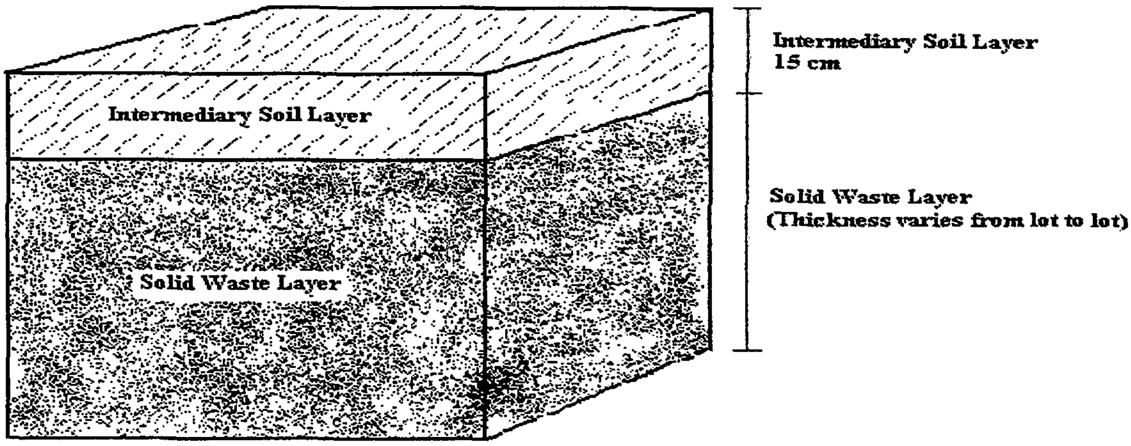


Figure 8.4. Representation of the final solid waste lift introduced into the HELP model system when the related lot is closed to solid waste disposal (Schroeder et al.. 1997)

The hydrological properties of the solid waste and intermediary soil layer disposed to Lot-1. Lot-2. and Lot-3 annually are given in Table 8.6. As discussed previously. the given solid waste height represents the annual total height of the solid waste layer and the daily soil cover is assumed to be layered at the end of each disposal year in the form of intermediary soil layer.

Table 8.6. Hydrological properties of solid waste and intermediary soil layers disposed to Lot-1, Lot-2 and Lot-3 annually

Layer Number	Layer Name	Properties of Layers
1	Intermediary Soil Layer	Type 1 – Vertical Percolation Layer Silty Clay 20 cm Porosity = 0.4520 vol/vol[1] Field Capacity = 0.4110 vol/vol[1] Wilting Point = 0.3110 vol/vol[1] Initial Soil Water Content = 0.4520[2] Effective Saturated Hydraulic Conductivity = 0.1×10[illegible] cm/sec[1]
2	Municipal Solid Waste Layer	Type 1 – Vertical Percolation Layer Compacted Municipal Solid Waste 200 cm Porosity = 0.6710 vol/vol[1] Field Capacity = 0.2920 vol/vol[1] Wilting Point = 0.0770 vol/vol[1] Initial Soil Water Content = 0.2920 vol/vol[2] Effective Saturated Hydraulic Conductivity = 1.0×10^{-3} cm/sec[1]

[1]These values of porosity, field capacity, wilting point and saturated hydraulic conductivity are HELP Model default values..

[2]Moisture values obtained at the end of the previous one year model runs.

8.2.3.4. Hydrological Properties of the Final Cap Designs for Lot-1, Lot-2 and Lot-3 : Municipal solid waste landfill final cap design data used in the HELP model are given in Table 8.7. Referring to Figure 5.3, municipal waste landfill final cap design suggested by Turkish Solid Waste Regulation published in 1991, is given in Table 5.18. Regarding the final caps, it should be noted that the related regulations make suggestions only on the designs and the hydraulic conductivity of the compacted clay layer, but not the soil parameters for the other layers of the final cap.

Unlike the Solid Waste Regulation of 1991, the municipal waste landfill's final caps, as suggested by the Turkish Solid Waste Regulation Revisions enacted in 2000, require an additional lateral drainage layer with a minimum thickness of 30 cm, and a compacted clay layer having a saturated hydraulic conductivity of 1×10^{-6} cm/sec. Moreover, 2 mm thick geomembrane layer installation is suggested by this latest revision.

Table 8.7. Hydrological properties of municipal solid waste landfill final cap design for Lot-1, Lot-2 and Lot-3

Layer Number	Layer Name	Properties of Layers
1	Agricultural Soil Layer	Type 1 – Vertical Percolation Layer Agricultural Soil – Loam - Silty Loam 100 cm Porosity = 0.5010 vol/vol[1] Field Capacity = 0.2840 vol/vol[1] Wilting Point = 0.1350 vol/vol[1] Initial Soil Water Content = 0.2882 vol/vol[2] Effective Saturated Hydraulic Conductivity = 1.9×10^{-4} cm/sec[1]
2	Drainage Layer	Type 2 – Lateral Drainage Layer 15 / 40 mm Gravel 60 cm Porosity = 0.3200 vol/vol[1] Field Capacity = 0.0500 vol/vol[1] Wilting Point = 0.0200 vol/vol[1] Initial Soil Water Content = 0.0771 vol/vol[2] Effective Saturated Hydraulic Conductivity = 0.2000 cm/sec[4]
3	Clay Layer	Type 3 – Barrier Soil Liner 60 cm Silty Clay Porosity = 0.4520 vol/vol[1] Field Capacity = 0.4110 vol/vol[1] Wilting Point = 0.3110 vol/vol[1] Initial Soil Water Content = 0.4520 vol/vol[2] Effective Saturated Hydraulic Conductivity = 0.12×10^{-5} cm/sec[1]
4	Gas Drainage Layer	Type 1 – Vertical Percolation Layer 15 / 40 mm Gravel 30 cm Porosity = 0.3200 vol/vol[1] Field Capacity = 0.0500 vol/vol[1] Wilting Point = 0.0200 vol/vol[1] Initial Soil Water Content = 0.0500 vol/vol[2] Effective Saturated Hydraulic Conductivity = 0.2000 cm/sec[4]
5	Stabilizing (Barrier) Soil Layer	Type 3 – Barrier Soil Liner Silty Loam – Loam 30 cm Porosity = 0.4370 vol/vol[3] Field Capacity = 0.0620 vol/vol[3] Wilting Point = 0.0240 vol/vol[3] Initial Soil Water Content = 0.4370 vol/vol[2] Effective Saturated Hydraulic Conductivity = 5.8×10^{-3} cm/sec[3]

[1]Values suggested by the HELP model manual (Schroeder et al., 1997) . These values of porosity, field capacity, wilting point and saturated hydraulic conductivity are used since no laboratory tests were performed on these layers. Values suggested by HELP manual for these types of layers are obtained from extensive studies and tests on various types of landfill layers in U.S.A.

[2]Moisture values obtained at the end of the previous one year model runs.

[3]These values of porosity, field capacity, wilting point and saturated hydraulic conductivity are HELP Model default values.

[4]Values chosen based upon the Turkish Solid Waste Regulations (Turkish Solid Waste Regulation, 1991).

8.2.4. Results of the HELP Model

The leachate generation in Sinop Sanitary Landfill is modeled for 3 periods.

- Leachate generation before the operation (Open Lot),
- Leachate generation during the operation (Active Lot),
- Leachate generation after the closure (Closed Lot).

8.2.4.1. Leachate Generation from Lot-1: The active life period of Lot-1 is 15 years. (between 2000 and 2015). It is opened in 1999, activates between 2000-2014 and will be closed at the end of 2014. The model results are given in Figure 8.5a. and 8.5b.

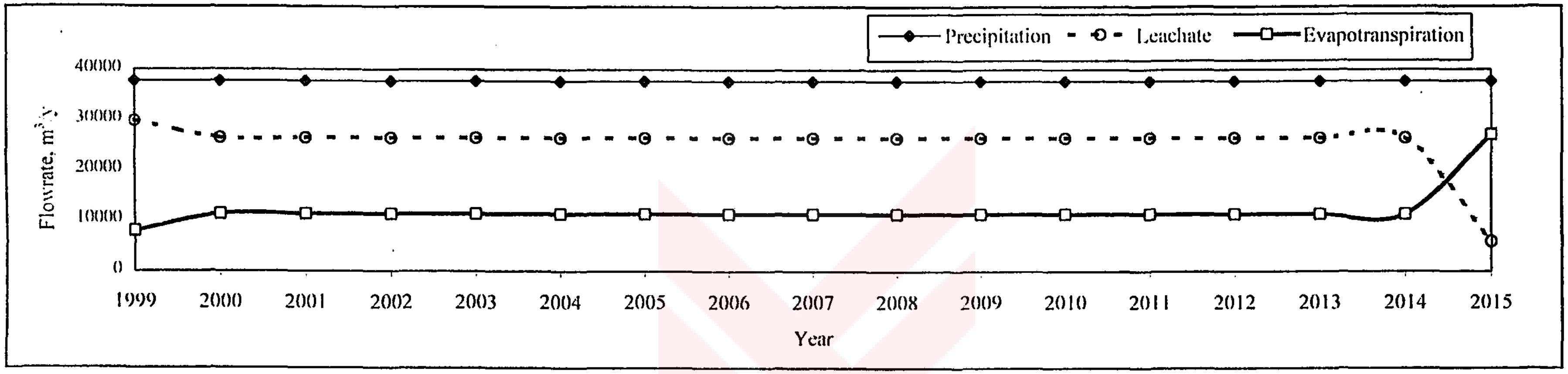
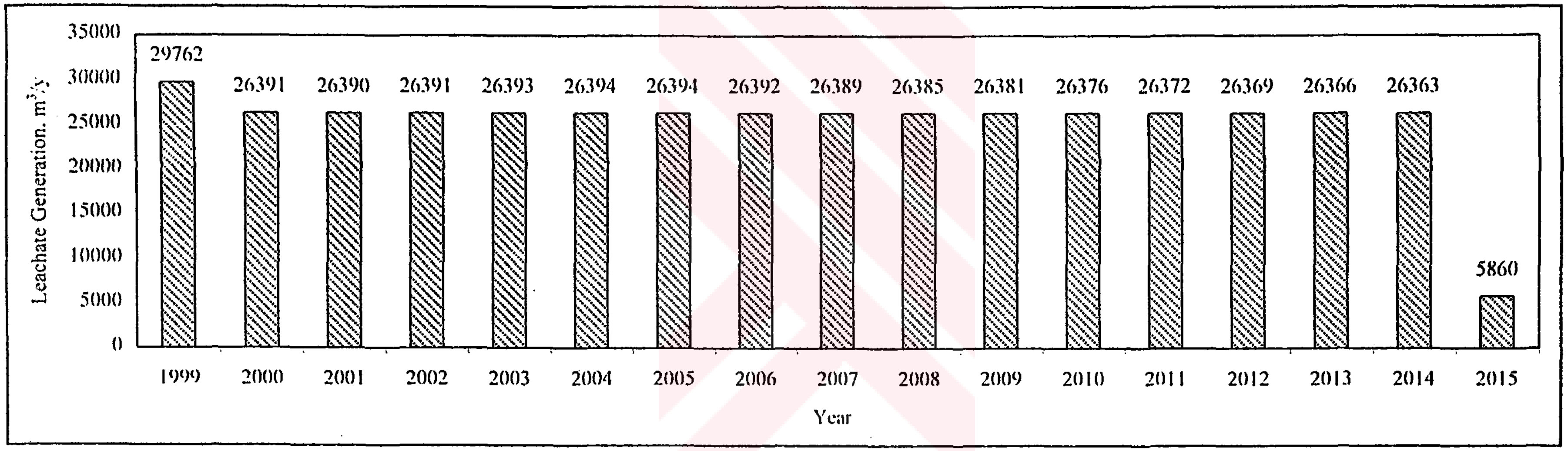


Figure 8.5a. Annual amount of precipitation, leachate and evapotranspiration in Lot-1 (HELP model)



Notes : 1 - Year 1999 data represents the leachate generation before the operation.
2 - Years 2000 - 2014 data represent the leachate generation during the operation.
3 - Year 2015 data represents the leachate generation after the closure.

Figure 8.5b. Annual leachate generation in Lot-1 (HELP model)

8.2.4.2. Leachate Generation from Lot-2 : The active life period of Lot-2 is 13 years, between 2015 and 2028. It will be opened in 2014, will activate between 2015-2027 and will be closed at the end of 2027. The model results are given in Figure 8.6a. and 8.6b.

8.2.4.3. Leachate Generation from Lot-3 : The active life period of Lot-3 is 3 years, between 2028 and 2030. It will be opened in 2027, will activate between 2028-2030 and will be closed at the end of 2028. The model results are given in Figure 8.7a. and 8.7b.

The annual leachate generation through the whole project, between 1999 – 2031 is given in Figure 8.8a. and 8.8b. These data involves the total leachate genearation in Lot-1, Lot-2 and Lot-3. The influent annual flowrate to the wastewater treatment plant is obtained from these data.

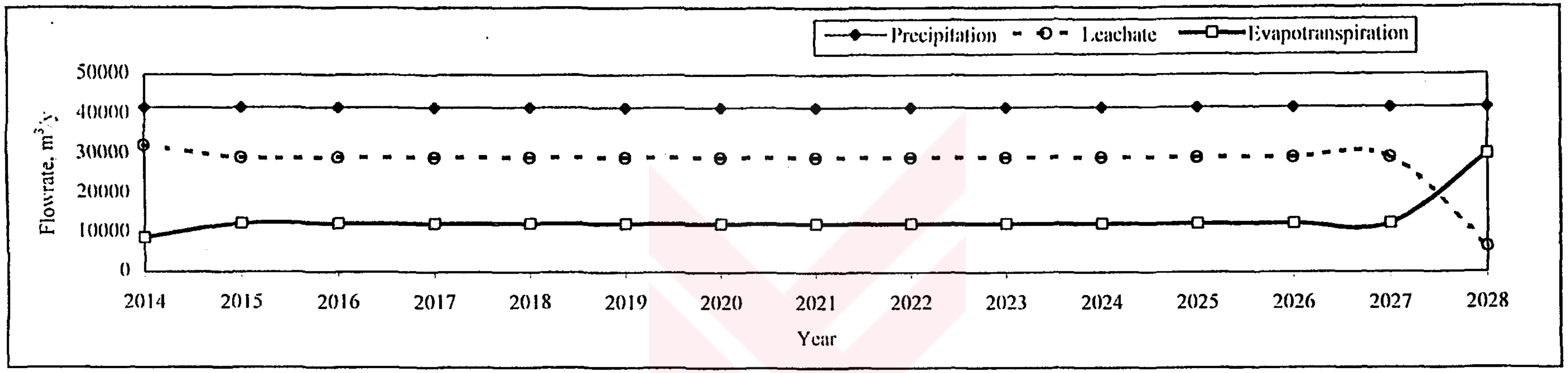
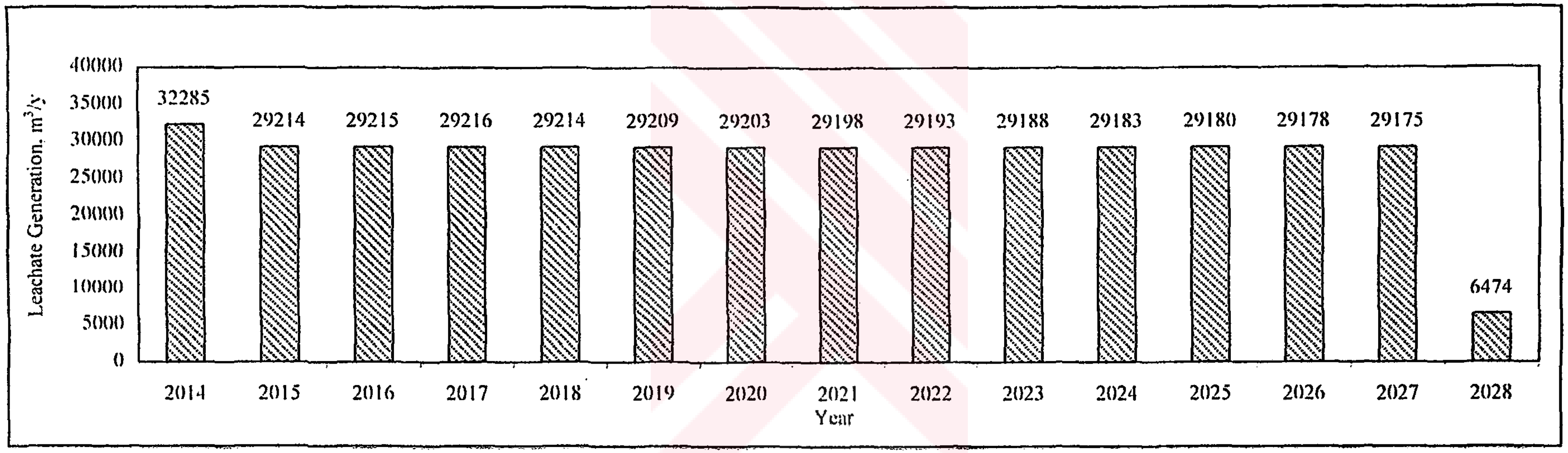


Figure 8.6a. Annual amount of precipitation, leachate and evapotranspiration in Lot-2 (HELP model)



Notes : 1 - Year 2014 data represents the leachate generation before the operation.
2 - Years 2015 - 2027 data represent the leachate generation during the operation.
3 - Year 2028 data represents the leachate generation after the closure.

Figure 8.6b. Annual leachate generation in Lot-2 (HELP model)

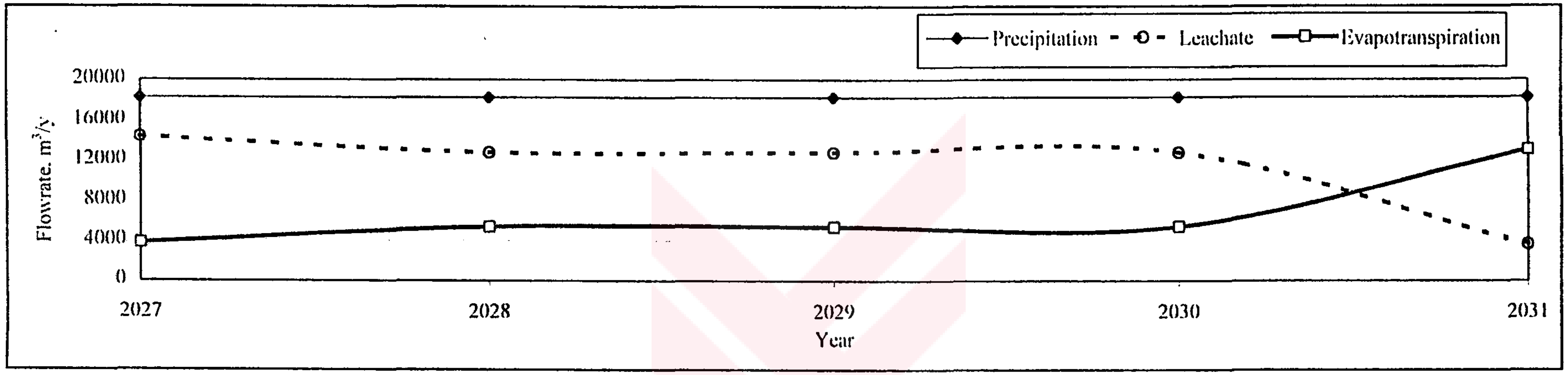
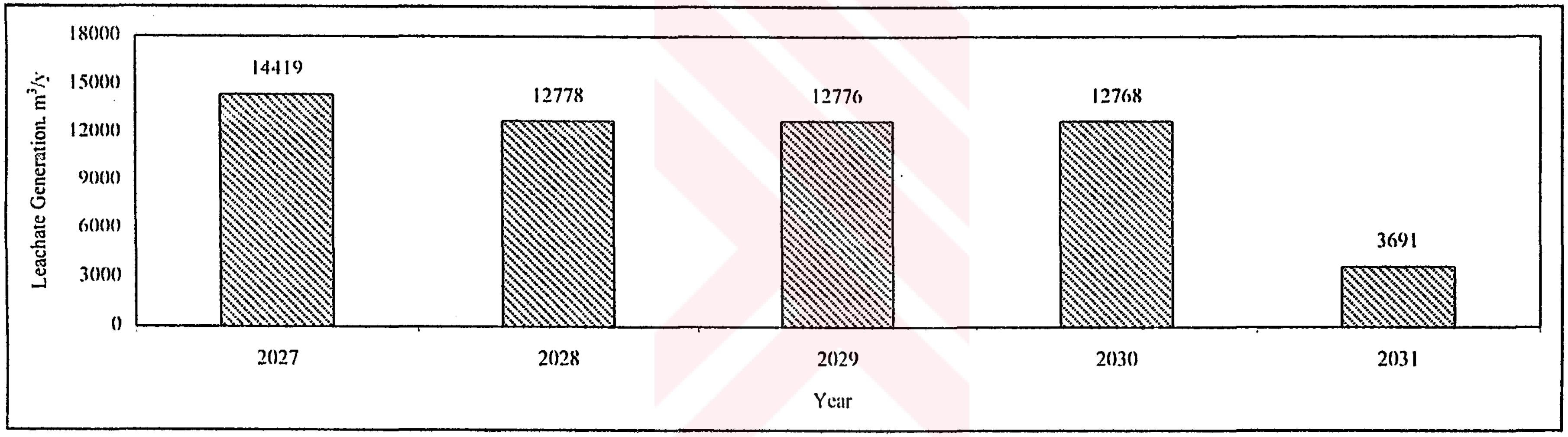


Figure 8.7a. Annual amount of precipitation, leachate and evapotranspiration in Lot-3 (HELP model)



Notes : 1 - Year 2027 data represents the leachate generation before the operation.
2 - Years 2028 - 2030 data represent the leachate generation during the operation.
3 - Year 2031 data represents the leachate generation after the closure.

Figure 8.7b. Annual leachate generation in Lot-3 (HELP model)

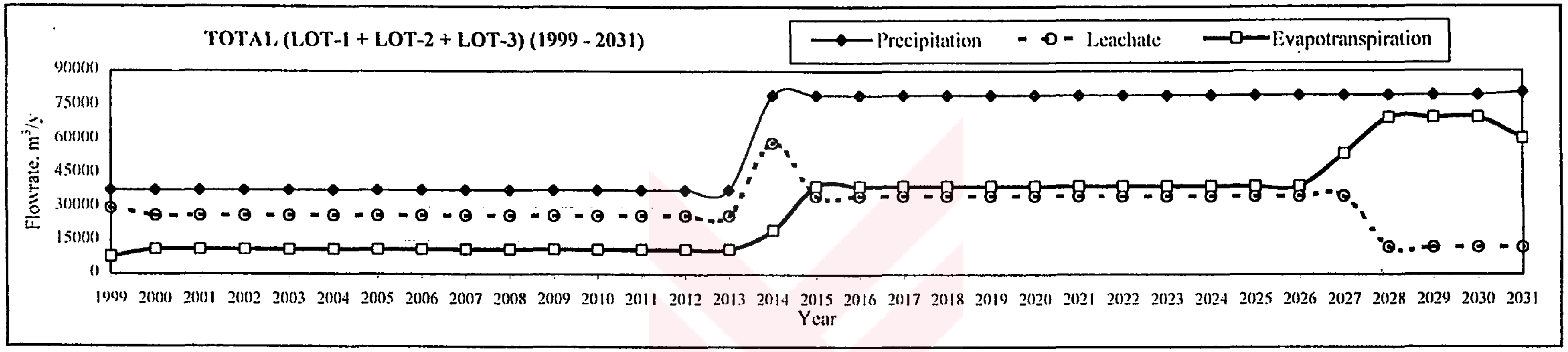
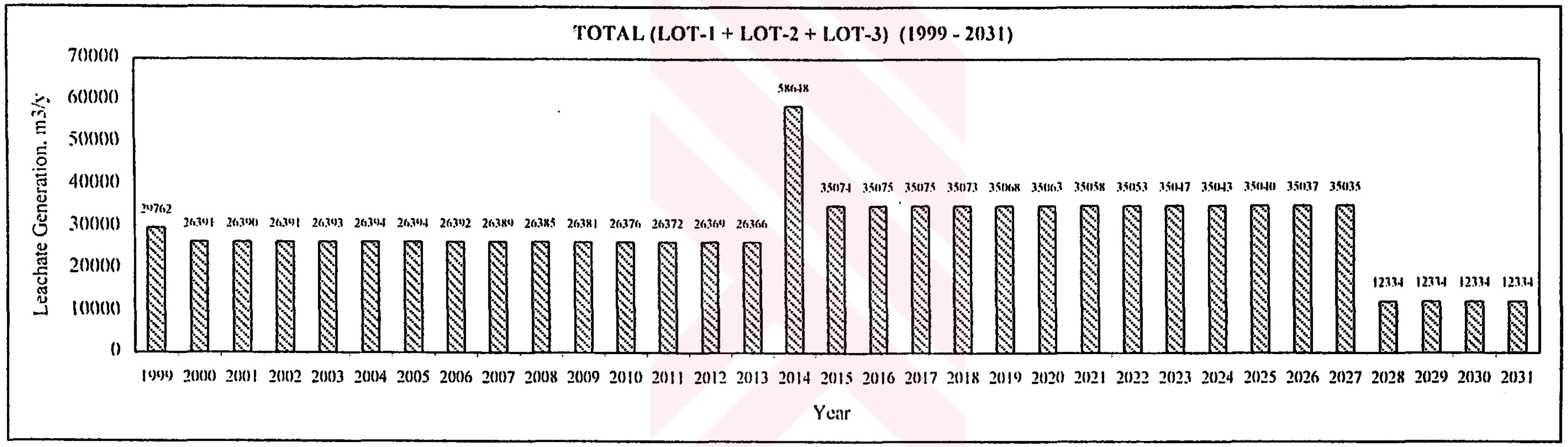


Figure 8.8a Annual total amount of precipitation, leachate and evapotranspiration in Lot-1, Lot-2 and Lot-3 (HELP model)



Notes : 1 - Year 2027 data represents the leachate generation before the operation.
2 - Years 2028 - 2030 data represent the leachate generation during the operation.
3 - Year 2031 data represents the leachate generation after the closure.

Figure 8.8b. Annual total leachate generation in Lot-1, Lot-2 and Lot-3 (HELP model)

8.3. Development of Water Balance Model, Input Data and Results

The water balance model is based on the Thornthwaite formula (Thornthwaite et al., 1955) to calculate potential evapotranspiration and the Benfratello formula (Canziani et al., 1989) to calculate the monthly percolation quantity in landfills. However, this model does not consider moisture to be held by the landfill layers. Thus, the amount of the percolating liquid is accepted as the total leachate quantity generated from the landfill.

Several empirical/theoretical equations are available for estimating the potential evapotranspiration and leachate generation rate in the landfills. However, Thornthwaite-Benfratello equations were chosen since they use an exponential relationship between mean monthly temperature and mean monthly heat index. Moreover, Thornthwaite-Benfratello method was especially developed for determining the rate of effective evapotranspiration in European climates and is widely used to predict evapotranspiration from landfill cover. Additionally, this method was further developed by providing additional tables necessary for calculation (Thornthwaite et al., 1955).

In the calculation of effective evapotranspiration, the progressive dehydration of agricultural soil is considered in the model by the formula developed by Benfratello. During the calculation, the monthly deficit/excess is obtained by subtracting the potential evapotranspiration (Pei) from the rainfall (Pi) minus runoff (Ri). A deficit occurs if $Pi-Ri-Pei < 0$ and is referred as the dry periods. In the same manner, the wet period exists when $Pi-Ri-Pei>0$. It has been observed from the results that the model does not generate values for leachate quantity during the periods of water deficit (dry periods) since the evapotranspiration is calculated less than the potential evapotranspiration. Thus, model calculates a value of zero for the dry periods.

8.3.1. Input Data

Potential evapotranspiration results obtained from the water balance model were generated based on Sinop's mean temperature data and are presented in Table 8.8. Consequently, by using the potential evapotranspiration data and the monthly precipitation data, runoff and percolation quantities are calculated by the water balance model based on potential evapotranspiration. During modeling, runoff coefficient is assumed as 0.22 which is a suggested value for vegetated landfill covers with a slope of 25%. Runoff and percolation quantities are presented in Table 8.9.

Table 8.8. Potential evapotranspiration calculation results of water balance model by using Thornthwaite formula (Thornthwaite et al., 1955)

Months	Mean Temperature	Thermal Index	Potential Evapotranspiration	Correction Coefficient	Corrected Potential Evapotranspiration
	(°C)		(mm)	(N hours)	(mm)
January	6.9	1.628	20.849	0.946	19.723
February	6.6	1.522	19.069	1.063	20.271
March	7.10	1.700	22.080	1.190	26.275
April	10.30	2.987	46.597	1.337	62.300
May	14.60	5.065	93.866	1.454	136.481
June	19.40	7.789	166.080	1.514	251.445
July	22.40	9.684	221.652	1.484	328.932
August	22.60	9.815	225.643	1.384	312.290
September	19.60	7.911	169.535	1.257	213.106
October	15.90	5.763	111.396	1.113	123.984
November	12.60	4.052	69.834	0.986	68.857
December	9.30	2.559	37.959	0.916	34.771
Totals		60.475		Total	1598.433
Thorthwaite coefficient		2.01	THORNTHWAITE FORMULA HAS BEEN USED		

Table 8.9. Results of monthly average runoff and percolation quantity

Months	Average Precipitation	Runoff	Average Percolation
	(mm)	(mm)	(mm)
January	73.8	16.236	37.84
February	50.5	11.110	19.12
March	46.7	10.274	10.15
April	39.2	8.624	0
May	35.3	7.766	0
June	34.2	7.524	0
July	31.1	6.842	0
August	40.4	8.888	0
September	63.2	13.904	0
October	80.7	17.754	0
November	88.7	19.514	0.33
December	86.2	18.964	32.56
Totals	670	147	100
Runoff Coefficient (c) 0.22	Total Leachate (mm/year)		100
Max. Percolation Capacity (mm/year) :	20	**Total Leachate (mm/year)**	**100**
Resistance to Desaturation Coefficient (m) :	1.5	the value of the exponent "m" lies between 1.25 & 1.75 m=0 immediately after rainfall	
Max. Volume of Water Soil Strata (exploited by roots) could contain (U - mm) :		130	
For agricultural land of medium sandy soil cultivated with maize. (U=105 mm.)			
BENFRATELLO FORMULA HAS BEEN USED IN THIS LEACHATE QUANTITY PREDICTION MODEL			

8.3.2. Results of Water Balance Model

The water balance model was calculated the leachate generation rate as 100 mm/year. For every lot, the annual leachate generation is calculated as below :

8.3.2.1. Leachate Generation from Lot-1 :

Area of Lot-1 = 5.45 ha = 54,500 m^2

Annual Leachate Generation = 100 mm/yr x 10^{-3} x 54,500 m^2 = 5,450 m^3/year

8.3.2.2. Leachate Generation from Lot-2 :

Area of Lot-2 = 6.03 ha = 60,300 m^2

Annual Leachate Generation = 100 mm/yr x 10^{-3} x 60,300 m^2 = 6,030 m^3/year

8.3.2.3. Leachate Generation from Lot-3 :

Area of Lot-3 = 2.64 ha = 26,400 m^2

Annual Leachate Generation = 100 mm/yr x 10^{-3} x 26,400 m^2 = 2,640 m^3/year

The summary of the leachate generation calculated by HELP and Water Balance Methods is given for each lots in Table 8.10.

Table 8.10. The overall summary of leachate generation results calculated by HELP and Water Balance models (m^3/yr)

	LOT-1	LOT-2	LOT-3
HELP Model	5,860 – 29,762	6.474 – 32.285	3,691 – 14,419
Water Balance Model	5.450	6,030	2,640

8.4. Evaluation of Leachate Generation Results

In this study, HELP and Water Balance Models are used for the estimation of leachate generation and the results are given in Table 8.10. Taking into account all the advantages and limitations of the two models, the HELP model should be preferred for landfill water budget analysis, despite the extra effort needed to simulate the results.

HELP model calculates leachate generation for an open lot, active lot and closed lot. However, the results of Water Balance model gives an average leachate generation for only an active lot. The leachate generation rate is higher during the active life of the landfill and is reduced gradually after the construction of the final cover. Also, annual leachate quantities calculated by Water Balance Model is about 18% of the annual leachate quantities calculated by HELP model. HELP was generated more realistic results. Therefore, HELP model should be preferred for landfill water balance analysis.

For these reasons, the model results were mainly organized around the HELP model since HELP can generate more realistic results on landfill leachate generation quantities.

8.5. Design of Leachate Collection System

Leachate quantity depends generally on precipitation. Leachate generation estimation rate before the closure of a landfill is needed to determine the spacing of the leachate collection pipes at the base of the landfill, the size of the leachate collection tank, and the design of an on site/off site plant for the leachate treatment. The leachate generation rate is higher during the active life of the landfill and is reduced gradually after the construction of the final cover.

According to the Bank of Provinces' technical specification, the leachate collection system is planned to receive all rain water and the leachate generating from solid waste.

The leachate collection pipes placed into the trenches and the minimum pipe diameter will be 150 mm. The slope of the pipes will be 1% and over the pipes, a layer of 30 cm height 15/40 mm granular material will be covered. The distance between the pipes will not exceed 100 m.

Rational Method is used in the design of leachate collection pipes. The basic equation in this method is given below :

$$Q = C \cdot I \cdot A \qquad (8.4)$$

where,

Q : Project flowrate, l/s

C : Surface runoff coefficient

I : Average rainfall intensity, l/s/ha

A : Drainage area, ha

In Rational Method, the rainfall intensity is the function of the collecion time (T, min). The collection time is equal to;

$$T = t_1 + t_2 \quad (8.5)$$

where,

t_1 : The time till the flow coming from the area enters the beginning of the collection system (min).

t_2 : The flow time of the cumulative flow from beginning to the end point (min).

In this thesis, the 2-year rainfall with 30 minutes was taken as a basis. Therefore, "t_1" entering time in the first pipe is taken as 30 minutes.

Flow time "t_2" was calculated as a function of "V", flow velocity and "Q", flowrate with the formula given below:

$$t_2 = L / (60 V) \quad (8.6)$$

where,

t_2 : Flow time, min

L : The distance between the manholes, m

V : Flow velocity, m/sn

If there are secondary pipelines connected to the main pipeline, then the flow time through the pipe which has the largest drainage area will be used in the design of the pipes.

After the calculation of the flowrates, pipe diameters were chosen. Then, by checking the flow velocity "V", "Q/Qd" and "h/d" values the chosen diameters were verified.

In order to explain more about the calculation steps of leachate generation, an example for Lot-1 is given below.

Example : Calculation of Leachate Generation in Lot-1, Manholes B4-B7 (see Table 8.11)

Input Data

Manholes; from B4 to B7
Total Drainage Area(A); 0.294 ha
Distance between B4 and B7 (X); 34 m
Inlet time (t); 30 min.
Rainfall intensity (i); 82 lt/sec/ha
Runoff coefficient (C); 1
Invert Level at B1 (L_{B1}); 66.60 m. and at B4 (L_{B4}); 69.45 m.

Calculation of Pipe Slope

The slope is calculated by the dividing the invert level difference (L_{B4}-L_{B1}) to the distance between B4 and B7 (X). Then;

$$\text{Slope } (1/A) = 1 / [(L_{B1} - L_{B4}) / X]$$
$$= 1 / [(69.45 - 66.60) / 34] = 0.0838 \qquad A = 11.93$$

Calculation of Flowrate

There are three connections to the pipe B4-B7 (Figure 8.1). These are B1-B4; B2-B4 and B3-B4 pipes. As it is mentioned above (If there are secondary pipelines connected to the main pipeline, then the flow time through the pipe which has the largest drainage area will be used in the design of the pipes) B3-B4 pipe carries the flow of the largest drainage area. So, the flow time at B3-B4 (30.56 min.) is accepted as equal to t_2 value for B4-B7. Then;

Flow time (t_1) = 0.23 min.
Inlet time (t_2) = 30.56 min.
Total time (T) = 30.78 min.

The rainfall intensity matching the total time (30.78 min.) was found from the "Data Table Generated According to Meteorological Observation Curve" as equal to 80.89 l/sec/ha (2 year, 30.78 min. rainfall). Finally, the flowrate was calculated :

$Q = C \, . \, I \, . \, A$

$Q = 1 \, . \, 80.89$ l/sec/ha . 0.294 ha = 23.78 l/sec.

The calculations and the results for each lot are given in Tables 8.11, 8.12, 8.13 and 8.14 and in Figure 8.9 the general layout of leachate collection system is presented.

Table 8.11. Lot-1 pre-closure leachate generation and collection, calculation table (2 year, 30 min. rainfall)

Region No.	From	To	Distance Between Manholes	Partial Area	Regions which Flows to the Area	Region where the Stormwater Runs	Total Drainage Area	Rainfall Intensity (	Runoff Coefficient	Stormwater from Unit Area	Stormwater from Total Area Q = Z F x q	LEVELS: Gravel Level Beginning	LEVELS: Gravel Level End	LEVELS: Invert Level Beginning	LEVELS: Invert Level End	LEVELS: Top Level of the Pipe Beginning	LEVELS: Top Level of the Pipe End	The Height of the Gravel Layer over the Pipe (2 x d) Beginning	The Height of the Gravel Layer over the Pipe (2 x d) End	Diameter	The Chosen Cross-Section: Slope - Capacity - Velocity			Investigations: $\frac{Q}{Q_d}$	Investigations: $\frac{V}{V_d}$	Investigations: $\frac{h}{d}$	Minimum Height	Velocity	Runoff Time	Inlet Time	Total Time
			L	F			Z F	i	Ψ	q	Q	Beginning	End	Beginning	End	Beginning	End	Beginning	End	d	J	Q_d	V_d				h	V	t2	t1	T
			m	ha			ha	lt/sec/ha		lt/sec/ha	lt/sec	m	m	m	m	m	m	m	m	cm	‰	lt/sec	m/sec	-	-	-	m	m/sec	min	min	min
1	B1	B4	38,00	0,084		4	0,084	82,00	1	82,00	6,89	73,70	70,10	73,10	69,50	73,30	69,70	0,40	0,40	20	10,56	103,02	3,28	0,07	0,57	0,18	0,04	1,86	0,34	30,00	30,34
2	B2	B4	39,00	0,100		4	0,100	82,00	1	82,00	8,20	72,60	70,10	72,00	69,50	72,20	69,70	0,40	0,40	20	15,60	84,71	2,70	0,10	0,63	0,21	0,04	1,71	0,38	30,00	30,38
3	B3	B4	58,00	0,110		4	0,110	82,00	1	82,00	9,02	73,70	70,10	73,10	69,50	73,30	69,70	0,40	0,40	20	16,11	83,35	2,65	0,11	0,65	0,22	0,04	1,74	0,56	30,00	30,56
4	B4	B7	34,00		1,2,3	7	0,294	80,89	1	80,89	23,78	70,20	67,35	69,45	66,60	69,70	66,85	0,50	0,50	25	11,93	175,41	3,57	0,14	0,70	0,25	0,06	2,50	0,23	30,56	30,78
5	B5	B7	53,00	0,136		7	0,136	82,00	1	82,00	11,15	70,60	67,25	70,00	66,65	70,20	66,85	0,40	0,40	20	15,82	84,12	2,68	0,13	0,69	0,25	0,05	1,86	0,48	30,00	30,48
6	B6	B7	35,00	0,196		7	0,196	82,00	1	82,00	16,07	69,10	67,25	68,50	66,65	68,70	66,85	0,40	0,40	20	18,92	76,91	2,45	0,21	0,79	0,31	0,06	1,94	0,30	30,00	30,30
7	B7	B10	55,00		4,5,6	10	0,626	80,43	1	80,43	50,35	67,35	60,75	66,60	60,00	66,85	60,25	0,50	0,50	25	8,33	209,93	4,28	0,24	0,82	0,33	0,08	3,51	0,26	30,78	31,04
8	B8	B10	85,00	0,364		10	0,364	82,00	1	82,00	29,85	68,60	60,65	68,00	60,05	68,20	60,25	0,40	0,40	20	10,69	102,37	3,26	0,29	0,87	0,37	0,07	2,83	0,50	30,00	30,50
9	B9	B10	21,00	0,134		10	0,134	82,00	1	82,00	10,99	63,60	60,65	63,00	60,05	63,20	60,25	0,40	0,40	20	7,12	125,50	3,99	0,09	0,62	0,20	0,04	2,46	0,14	30,00	30,14
10	B10	B20	53,00	0,056	7,8,9	20	1,180	79,91	1	79,91	94,29	60,75	55,75	60,00	55,00	60,25	55,25	0,50	0,50	25	10,60	186,11	3,79	0,51	1,00	0,50	0,13	3,80	0,23	31,04	31,28
11	B11	B20	61,00	0,377		20	0,377	82,00	1	82,00	30,91	60,60	55,65	60,00	55,05	60,20	55,25	0,40	0,40	20	12,32	95,31	3,03	0,32	0,89	0,39	0,08	2,71	0,38	30,00	30,38
12	B12	B20	57,00	0,192		20	0,192	82,00	1	82,00	15,74	60,60	55,65	60,00	55,05	60,20	55,25	0,40	0,40	20	11,52	98,63	3,14	0,16	0,73	0,27	0,05	2,30	0,41	30,00	30,41
13	B13	B16	55,00	0,076		16	0,076	82,00	1	82,00	6,23	74,50	67,10	73,90	66,50	74,10	66,70	0,40	0,40	20	7,43	122,81	3,91	0,05	0,52	0,15	0,03	2,05	0,45	30,00	30,45
14	B14	B16	60,00	0,215		16	0,215	82,00	1	82,00	17,63	69,10	67,10	68,50	66,50	68,70	66,70	0,40	0,40	20	30,00	61,03	1,94	0,29	0,87	0,37	0,07	1,68	0,60	30,00	30,60
15	B15	B16	52,00	0,200		16	0,200	82,00	1	82,00	16,40	70,10	67,10	69,50	66,50	69,70	66,70	0,40	0,40	20	17,33	80,36	2,56	0,20	0,79	0,31	0,06	2,01	0,43	30,00	30,43
16	B16	B19	27,00		13,14,15	19	0,491	80,81	1	80,81	39,68	67,20	62,75	66,45	62,00	66,70	62,25	0,50	0,50	25	6,07	246,08	5,01	0,16	0,73	0,27	0,07	3,68	0,12	30,60	30,72
17	B17	B19	33,00	0,123		19	0,123	82,00	1	82,00	10,09	63,60	62,65	63,00	62,05	63,20	62,25	0,40	0,40	20	34,74	56,71	1,81	0,18	0,76	0,29	0,06	1,36	0,40	30,00	30,40
18	B18	B19	57,00	0,192		19	0,192	82,00	1	82,00	15,74	64,60	62,65	64,00	62,05	64,20	62,25	0,40	0,40	20	29,23	61,83	1,97	0,25	0,84	0,34	0,07	1,64	0,58	30,00	30,58
19	B19	B20	41,00	0,061	16,17,18	20	0,867	80,57	1	80,57	69,85	62,75	55,75	62,00	55,00	62,25	55,25	0,50	0,50	25	5,86	250,47	5,10	0,28	0,86	0,36	0,09	4,37	0,16	30,72	30,87
20	B20	B28	62,00	0,279	10,11,12,19	28	2,895	79,45	1	79,45	230,00	55,85	50,90	54,95	50,00	55,25	50,30	0,60	0,60	30	12,53	277,75	3,93	0,83	1,12	0,69	0,21	4,39	0,24	31,28	31,51
21	B21	B23	76,00	0,117		23	0,117	82,00	1	82,00	9,59	73,90	66,80	73,30	66,20	73,50	66,40	0,40	0,40	20	10,70	102,31	3,26	0,09	0,63	0,21	0,04	2,04	0,62	30,00	30,62
22	B22	B23	74,00	0,380		23	0,380	82,00	1	82,00	31,16	70,10	66,80	69,50	66,20	69,70	66,40	0,40	0,40	20	22,42	70,62	2,25	0,44	0,97	0,46	0,09	2,18	0,57	30,00	30,57
23	B23	B25	68,00	0,080	21,22	25	0,577	80,76	1	80,76	46,60	66,90	62,25	66,15	61,50	66,40	61,75	0,50	0,50	25	14,62	158,40	3,23	0,29	0,87	0,37	0,09	2,81	0,40	30,62	31,02
24	B24	B25	68,00	0,340		25	0,340	82,00	1	82,00	27,88	64,60	62,15	64,00	61,55	64,20	61,75	0,40	0,40	20	27,76	63,46	2,02	0,44	0,97	0,46	0,09	1,95	0,58	30,00	30,58
25	B25	B27	57,00	0,096	23,24	27	1,013	79,95	1	79,95	80,99	62,25	58,60	61,50	57,85	61,75	58,10	0,50	0,50	25	15,62	153,28	3,12	0,53	1,01	0,52	0,13	3,17	0,30	31,03	31,32
26	B26	B27	64,00	0,200		27	0,200	82,00	1	82,00	16,40	60,60	58,50	60,00	57,90	60,20	58,10	0,40	0,40	20	30,48	60,55	1,93	0,27	0,85	0,36	0,07	1,64	0,65	30,00	30,65
27	B27	B28	67,00	0,205	25,26	28	1,418	79,35	1	79,35	112,52	58,60	50,80	57,85	50,05	58,10	50,30	0,50	0,50	25	8,59	206,77	4,21	0,54	1,02	0,53	0,13	4,30	0,26	31,32	31,58
28	B28	B29	76,00		20,27	29	4,313	78,83	1	78,83	340,01	51,20	47,00	49,90	45,70	50,40	46,10	0,90	0,90	40	18,10	495,00	3,94	0,69	1,08	0,61	0,24	4,24	0,30	31,58	31,88

Table 8.12. Lot-2 Pre-closure leachate generation and collection, calculation table (2 year, 30 min.

Region No.	From	To	Distance Between Manholes	Partial Area	Regions which Flows to the Area	Region where the Stormwater Runs	Total Drainage Area	Rainfall Intensity	Runoff Coefficient	Stormwater from Unit Area	Stormwater from Total Area $Q = \Sigma F \times q$	LEVELS: Gravel Level		Invert Level		Top Level of the Pipe		The Height of the Gravel Layer over the Pipe (2 x d)		Diameter	The Chosen Cross-Section: Slope - Capacity - Velocity			Investigations: $\frac{Q}{Q_d}$	$\frac{V}{V_d}$	$\frac{h}{d}$	Minimum Height	Velocity	Runoff Time	Inlet Time	Total Time
			L	F			ΣF	i	Ψ	q	Q	Beginning	End	Beginning	End	Beginning	End	Beginning	End	d	J	Q_d	V_d				h	V	t2	t1	T
			m	ha			ha	lt/sec/ha		lt/sec/ha	lt/sec	m	m	m	m	m	m	m	m	cm	1:A	lt/sec	m/sec	-	-	-	m	m/sec	min	min	min
1	B1	B4	79,00	0,103		4	0,103	82,00	1	82,00	8,45	97,40	92,10	96,80	91,50	97,00	91,70	0,40	0,40	20	14,91	86,67	2,76	0,10	0,63	0,21	0,04	1,75	0,75	30,00	30,75
2	B2	B4	82,00	0,450		4	0,450	82,00	1	82,00	36,90	93,50	92,10	92,90	91,50	93,10	91,70	0,40	0,40	20	58,57	43,63	1,39	0,85	1,12	0,71	0,14	1,56	0,88	30,00	30,88
3	B3	B4	73,00	0,390		4	0,390	82,00	1	82,00	31,98	93,80	92,10	93,20	91,50	93,40	91,70	0,40	0,40	20	42,91	50,98	1,62	0,63	1,06	0,57	0,11	1,71	0,71	30,00	30,71
4	B4	B7	47,00		1,2,3	7	0,943	80,25	1	80,25	75,67	92,20	88,25	91,45	87,50	91,70	87,75	0,50	0,50	25	11,90	175,64	3,58	0,43	0,96	0,46	0,11	3,44	0,23	30,88	31,10
5	B5	B7	78,00	0,290		7	0,290	82,00	1	82,00	23,78	89,10	88,15	88,50	87,55	88,70	87,75	0,40	0,40	20	82,11	36,82	1,17	0,65	1,06	0,58	0,12	1,25	1,04	30,00	31,04
6	B6	B7	74,00	0,332		7	0,332	82,00	1	82,00	27,22	91,10	88,15	90,50	87,55	90,70	87,75	0,40	0,40	20	25,08	66,76	2,13	0,41	0,95	0,44	0,09	2,02	0,61	30,00	30,61
7	B7	B10	45,00		4,5,6	10	1,565	79,79	1	79,79	124,87	88,25	84,85	87,50	84,10	87,75	84,35	0,50	0,50	25	13,24	166,52	3,39	0,75	1,10	0,65	0,16	3,72	0,20	31,10	31,31
8	B8	B10	62,00	0,219		10	0,219	82,00	1	82,00	17,96	86,60	84,75	86,00	84,15	86,20	84,35	0,40	0,40	20	33,51	57,74	1,84	0,31	0,88	0,38	0,08	1,62	0,64	30,00	30,64
9	B9	B10	60,00	0,257		10	0,257	82,00	1	82,00	21,07	86,60	84,75	86,00	84,15	86,20	84,35	0,40	0,40	20	32,43	58,69	1,87	0,36	0,92	0,41	0,08	1,71	0,58	30,00	30,58
10	B10	B13	25,00		7,8,9	13	2,041	79,39	1	79,39	162,03	84,85	82,75	84,10	82,00	84,35	82,25	0,50	0,50	25	11,90	175,59	3,58	0,92	1,10	0,80	0,20	3,93	0,11	31,31	31,41
11	B11	B13	48,00	0,075		13	0,075	82,00	1	82,00	6,15	83,60	82,65	83,00	82,05	83,20	82,25	0,40	0,40	20	50,53	46,99	1,50	0,13	0,69	0,24	0,05	1,03	0,77	30,00	30,77
12	B12	B13	60,00	0,152		13	0,152	82,00	1	82,00	12,46	83,60	82,65	83,00	82,05	83,20	82,25	0,40	0,40	20	63,16	42,01	1,34	0,30	0,87	0,37	0,07	1,17	0,86	30,00	30,86
13	B13	B24	28,00		10,11,12	24	2,268	79,18	1	79,18	179,57	82,75	78,50	82,00	77,75	82,25	78,00	0,50	0,50	25	6,59	236,14	4,81	0,76	1,10	0,65	0,16	5,29	0,09	31,41	31,50
14	B14	B16	52,00	0,100		16	0,100	82,00	1	82,00	8,20	93,60	89,60	93,00	89,00	93,20	89,20	0,40	0,40	20	13,00	92,82	2,95	0,09	0,62	0,20	0,04	1,82	0,48	30,00	30,48
15	B15	B16	69,00	0,340		16	0,340	82,00	1	82,00	27,88	93,50	89,60	92,90	89,00	93,10	89,20	0,40	0,40	20	17,69	79,53	2,53	0,35	0,91	0,41	0,08	2,31	0,50	30,00	30,50
16	B16	B18	44,00	0,138	14,15	18	0,578	81,00	1	81,00	46,82	89,70	84,25	88,95	83,50	89,20	83,75	0,50	0,50	25	8,07	213,29	4,35	0,22	0,80	0,32	0,08	3,48	0,21	30,50	30,71
17	B17	B18	51,00	0,170		18	0,170	82,00	1	82,00	13,94	89,10	84,15	88,50	83,55	88,70	83,75	0,40	0,40	20	10,30	104,28	3,32	0,13	0,70	0,25	0,05	2,31	0,37	30,00	30,37
18	B18	B20	40,00	0,110	16,17	20	0,858	80,58	1	80,58	69,14	84,25	82,65	83,50	81,90	83,75	82,15	0,50	0,50	25	25,00	121,08	2,47	0,57	1,03	0,54	0,14	2,55	0,26	30,71	30,97
19	B19	B20	43,00	0,123		20	0,123	82,00	1	82,00	10,09	86,60	82,55	86,00	81,95	86,20	82,15	0,40	0,40	20	10,62	102,72	3,27	0,10	0,61	0,21	0,04	2,08	0,34	30,00	30,34
20	B20	B22	40,00	0,071	18,19	22	1,052	80,06	1	80,06	84,22	82,65	80,75	81,90	80,00	82,15	80,25	0,50	0,50	25	21,05	131,97	2,69	0,64	1,06	0,58	0,15	2,85	0,23	30,97	31,20
21	B21	B22	44,00	0,100		22	0,100	82,00	1	82,00	8,20	83,60	80,65	83,00	80,05	83,20	80,25	0,40	0,40	20	11,53	98,59	3,14	0,08	0,61	0,19	0,04	1,90	0,30	30,00	30,30
22	B22	B23	47,00	0,081	20,21	23	1,236	79,60	1	79,60	98,39	80,75	78,85	80,00	78,10	80,25	78,35	0,50	0,50	25	21,71	121,72	2,48	0,81	1,11	0,68	0,17	2,76	0,28	31,20	31,48
23	B23	B24	44,00	0,147	22	24	1,483	79,03	1	79,03	109,30	79,05	78,70	78,00	77,65	78,35	78,00	0,70	0,70	35	97,14	149,69	1,56	0,73	1,09	0,63	0,22	1,70	0,33	31,48	31,82
24	B24	B25	49,00	0,206	13,23	25	3,857	78,37	1	78,37	302,25	79,00	78,50	77,50	77,00	78,00	77,50	1,00	1,00	50	98,00	383,00	1,95	0,79	1,11	0,67	0,33	2,16	0,38	31,82	32,20
25	B25	B34	45,00	0,140	24	34	3,997	77,61	1	77,61	310,21	78,50	77,50	77,00	76,00	77,50	76,50	1,00	1,00	50	45,00	565,77	2,88	0,55	1,02	0,53	0,26	2,95	0,25	32,20	32,45
26	B26	B28	48,00	0,074		28	0,074	82,00	1	82,00	6,07	93,10	90,60	92,50	90,00	92,70	90,20	0,40	0,40	20	19,20	76,31	2,43	0,08	0,60	0,19	0,04	1,45	0,55	30,00	30,55
27	B27	B28	88,00	0,400		28	0,400	82,00	1	82,00	32,80	93,80	90,60	93,20	90,00	93,40	90,20	0,40	0,40	20	27,50	63,76	2,03	0,51	1,01	0,51	0,10	2,04	0,72	30,00	30,72
28	B28	B30	35,00	0,164	26,27	30	0,638	80,56	1	80,56	51,40	90,70	87,95	89,95	87,20	90,20	87,45	0,50	0,50	25	12,73	169,82	3,46	0,30	0,88	0,38	0,09	3,03	0,19	30,72	30,91
29	B29	B30	60,00	0,200		30	0,200	82,00	1	82,00	16,40	91,10	87,85	90,50	87,25	90,70	87,45	0,40	0,40	20	21,23	72,59	2,31	0,23	0,81	0,32	0,06	1,87	0,62	30,00	30,62
30	B30	B32	40,00	0,128	28,29	32	0,966	80,18	1	80,18	77,45	87,95	83,05	87,20	82,30	87,45	82,55	0,50	0,50	25	8,16	212,11	4,32	0,37	0,92	0,42	0,10	3,98	0,17	30,91	31,08
31	B31	B32	70,00	0,219		32	0,219	82,00	1	82,00	17,96	86,60	82,95	86,00	82,35	86,20	82,55	0,40	0,40	20	19,18	76,38	2,43	0,24	0,82	0,33	0,07	1,99	0,59	30,00	30,59
32	B32	B34	45,00	0,070	30,31	34	1,255	79,85	1	79,85	100,21	83,05	77,00	82,30	76,25	82,55	76,50	0,50	0,50	25	7,44	222,23	4,53	0,45	0,97	0,47	0,12	4,41	0,17	31,08	31,25
33	B33	B34	64,00	0,150		34	0,150	82,00	1	82,00	12,30	83,60	76,90	83,00	76,30	83,20	76,50	0,40	0,40	20	9,55	108,41	3,45	0,11	0,66	0,23	0,05	2,29	0,47	30,00	30,47
34	B34	B35	36,00		25,32,33	35	5,402	77,10	1	77,10	416,50	77,70	74,00	76,00	72,55	76,50	73,05	1,20	0,95	50	10,43	1176,21	5,99	0,35	0,91	0,41	0,21	5,48	0,11	32,45	32,56

Table 8.13. Lot-3 Pre-closure leachate generation and collection, calculation table (2 year, 30 min. rainfall)

Region No	From	To	Distance Between Manholes	Partial Area	Regions which Flows to the Area	Region where the Stormwater Runs	Total Drainage Area	Rainfall Intensity	Runoff Coefficient	Stormwater from Unit Area	Stormwater from Total Area $Q = Z F \times q$
			L	F			Z F	i	Ψ	q	Q
			m	ha			ha	lt/sec/ha		lt/sec/ha	lt/sec
1	B1	B4	52,00	0,079		4	0,079	82,00	1	82,00	6,48
2	B2	B4	67,00	0,240		4	0,240	82,00	1	82,00	19,68
3	B3	B4	76,00	0,400		4	0,400	82,00	1	82,00	32,80
4	B4	B12	50,00	0,024	1,2,3	12	0,743	80,60	1	80,60	59,88
5	B5	B8	29,00	0,055		8	0,055	82,00	1	82,00	4,51
6	B6	B8	61,00	0,160		8	0,160	82,00	1	82,00	13,12
7	B7	B8	47,00	0,160		8	0,160	82,00	1	82,00	13,12
8	B8	B10	41,00	0,035	5,6,7	10	0,410	80,47	1	80,47	32,99
9	B9	B10	66,00	0,300		10	0,300	82,00	1	82,00	24,60
10	B10	B11	50,00	0,260	8,9	11	0,970	80,03	1	80,03	77,63
11	B11	B12	30,00	0,260	10	12	1,230	79,10	1	79,10	97,30
12	B12	B14	33,00	0,300	4,11	14	2,273	78,64	1	78,64	178,76
13	B13	B14	44,00	0,120		14	0,120	82,00	1	82,00	9,84
14	B14	B15	35,00	0,086	12,13	15	2,479	78,17	1	78,17	193,78
15	B15	B16	41,00	0,050	14	16	2,529	77,73	1	77,73	196,57
16	B16	B17	20,00		15	17	2,529	77,00	1	77,00	194,73

Region No	LEVELS: Gravel Level		LEVELS: Invert Level		LEVELS: Top Level of the Pipe		The Height of the Gravel Layer over the Pipe (2 x d)		Diameter	The Chosen Cross-Section: Slope - Capacity - Velocity			Investigations: $\frac{Q}{Q_d}$	Investigations: $\frac{V}{V_d}$	Investigations: $\frac{h}{d}$	Minimum Height	Velocity	Runoff Time	Inlet Time	Total Time
	Beginning	End	Beginning	End	Beginning	End	Beginning	End	d	J	Q_d	V_d				h	V	t2	t1	T
	m	m	m	m	m	m	m	m	cm	I·A	lt/sec	m/sec	-	-	-	m	m/sec	min	min	min
1	87,10	83,10	86,50	82,50	86,70	82,70	0,40	0,40	20	13,00	92,82	2,95	0,07	0,58	0,18	0,04	1,70	0,51	30,00	30,51
2	85,60	83,10	85,00	82,50	85,20	82,70	0,40	0,40	20	26,80	61,59	2,06	0,30	0,88	0,38	0,08	1,80	0,62	30,00	30,62
3	85,10	83,10	84,50	82,50	84,70	82,70	0,40	0,40	20	38,00	51,21	1,73	0,61	1,05	0,56	0,11	1,81	0,70	30,00	30,70
4	83,20	78,25	82,45	77,50	82,70	77,75	0,50	0,50	25	10,10	190,65	3,88	0,31	0,89	0,38	0,10	3,44	0,24	30,70	30,94
5	88,60	84,60	88,00	84,00	88,20	84,20	0,40	0,40	20	7,25	124,35	3,96	0,04	0,47	0,13	0,03	1,87	0,26	30,00	30,26
6	87,70	84,60	87,10	84,00	87,30	84,20	0,40	0,40	20	19,68	75,41	2,40	0,17	0,75	0,28	0,06	1,80	0,56	30,00	30,56
7	85,10	84,60	84,50	84,00	84,70	84,20	0,40	0,40	20	94,00	34,40	1,09	0,38	0,93	0,43	0,09	1,02	0,77	30,00	30,77
8	84,70	79,65	83,95	78,90	84,20	79,15	0,50	0,50	25	8,12	212,69	4,33	0,16	0,73	0,27	0,07	3,15	0,22	30,77	30,98
9	80,90	79,75	80,00	78,85	80,30	79,15	0,60	0,60	30	57,39	129,52	1,83	0,19	0,77	0,30	0,09	1,41	0,78	30,00	30,78
10	79,95	79,20	78,75	78,00	79,15	78,40	0,80	0,80	40	66,67	257,53	2,05	0,30	0,88	0,38	0,15	1,79	0,46	30,98	31,45
11	79,20	78,55	78,00	77,35	78,40	77,75	0,80	0,80	40	46,15	309,66	2,46	0,31	0,89	0,39	0,15	2,18	0,23	31,45	31,68
12	78,55	78,00	77,35	76,80	77,75	77,20	0,80	0,80	40	60,00	271,50	2,16	0,66	1,07	0,59	0,24	2,31	0,24	31,68	31,92
13	81,20	77,60	80,60	77,00	80,80	77,20	0,40	0,40	20	12,22	95,73	3,05	0,10	0,64	0,22	0,04	1,96	0,37	30,00	30,37
14	78,00	77,20	76,80	76,00	77,20	76,40	0,80	0,80	40	43,75	318,08	2,53	0,61	1,05	0,56	0,23	2,65	0,22	31,92	32,14
15	77,20	76,70	76,00	75,50	76,40	75,90	0,80	0,80	40	88,00	221,05	1,78	0,88	1,13	0,73	0,29	2,01	0,36	32,14	32,50
16	77,20	76,70	75,50	75,00	75,90	75,40	1,30	1,30	40	40,00	332,69	2,65	0,59	1,0391	0,55	0,22	2,75	0,12	32,50	32,62

Table 8.14. Pre-closure leachate generation and collection for the main collector, calculation table (2 year, 30 min. rainfall)

Region No.	From	To	Distance Between Manholes	Regions which Flows to the Area	Region where the Stormwater Runs	Total Drainage Area	Rainfall Intensity	Runoff Coefficient	Stormwater from Unit Area	Stormwater from Total Area Q = Z F x q	LEVELS: Gravel Level		LEVELS: Invert Level		LEVELS: Top Level of the Pipe		The Height of the Gravel Layer over the Pipe (2 x d)		Diameter	The Chosen Cross-Section: Slope - Capacity - Velocity			Investigations: $\frac{Q}{Q_d}$	$\frac{V}{V_d}$	$\frac{h}{d}$	Minimum Height	Velocity
			L			Z F	i	Ψ	q	Q	Beginning	End	Beginning	End	Beginning	End	Beginning	End	d	J	Q_d	V_d				h	V
			m			ha	lt/sec/ha		lt/sec/ha	lt/sec	m	m	m	m	m	m	m	m	cm	1:A	lt/sec	m/sec	-	-	-	m	m/sec
34	B34	B1	36,00	LOT2-A	1	5,402	77,10	1	77,10	416,50	77,70	74,00	76,00	72,55	76,50	73,05	1,20	0,95	50	10,43	1176,21	5,99	0,35	0,91	0,41	0,21	5,48
1	B1	B2	61,00	92	2	5,402				416,50	74,00	67,00	72,55	65,50	73,05	66,00	0,95	1,00	50	8,65	1291,80	6,58	0,32	0,89	0,39	0,20	5,86
2	B2	B3	60,00	1	3	5,402				416,50	67,00	62,60	65,50	61,30	66,00	61,80	1,00	0,80	50	14,29	1005,08	5,12	0,41	0,95	0,45	0,22	4,88
3	B3	B4	59,00	2	4	5,402				416,50	62,60	57,50	61,30	55,90	61,80	56,40	0,80	1,10	50	10,93	1149,44	5,85	0,36	0,92	0,42	0,21	5,39
4	B4	B5	59,00	3	5	5,402				416,50	57,50	57,00	55,90	54,60	56,40	55,10	1,10	1,90	50	45,38	563,37	2,87	0,74	1,09	0,64	0,32	3,14
5	B5	B6	60,00	4	6	5,402				416,50	57,00	53,20	54,60	49,90	55,10	50,40	1,90	2,80	50	12,77	1063,29	5,42	0,39	0,94	0,43	0,22	5,09
6	B6	B11	37,00	5	11	5,402				416,50	53,20	47,00	49,90	45,70	50,40	46,20	2,80	0,80	50	8,81	1280,22	6,52	0,33	0,89	0,39	0,20	5,83
16	B16	B7	20,00	LOT2-B	7	2,529	77,00	1	77,00	194,73	77,20	76,70	75,50	75,00	75,90	75,40	1,30	1,30	40	40,00	332,69	2,65	0,59	1,04	0,55	0,22	2,75
7	B7	B8	60,00	93	8	2,529				194,81	76,70	69,40	75,00	68,10	75,40	68,50	1,30	0,90	40	8,70	714,41	5,69	0,27	0,85	0,36	0,14	4,84
8	B8	B9	61,00	7	9	2,529				194,81	69,40	65,00	68,10	63,70	68,50	64,10	0,90	0,90	40	13,86	565,64	4,50	0,34	0,91	0,40	0,16	4,08
9	B9	B10	60,00	8	10	2,529				194,81	65,00	48,90	63,70	47,60	64,10	48,00	0,90	0,90	40	3,73	1091,68	8,69	0,18	0,76	0,29	0,11	6,57
10	B10	B11	21,00	9	11	2,529				194,81	48,90	47,00	47,60	45,70	48,00	46,10	0,90	0,90	40	11,05	633,59	5,04	0,31	0,88	0,38	0,15	4,44
28	B28	B11	76,00	LOT1	11	4,313	78,83	1	78,83	340,01	51,20	47,00	49,90	45,70	50,30	46,10	0,90	0,90	40	18,10	588,91	4,69	0,45	0,98	0,47	0,19	4,57

Figure 8.9. General view of leachate collection system

9. DESIGN OF SURFACE WATER DRAINAGE SYSTEM

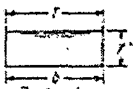
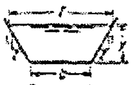
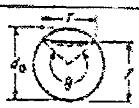
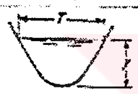
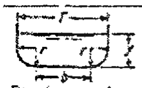
9.1. Surface Water Ditch

The management of all surface waters is very important in controlling the movement of leachate. Reduction of the amount of surface water that enters the landfill is of fundamental importance in the design of a sanitary landfill, because surface water is the major contributor to the total leachate quantity (Tchobanoglous et al., 1993).

All run-on water should be diversified away from the landfill by constructing drainage ditches. The design of a stormwater drainage ditch uses principles of open channel flow. There may be several ditches running over and around a landfill; in many instances one or more secondary ditches are connected to a primary drainage, which carries the entire runoff from the landfill area. In designing of these ditches care should be taken to estimate proper volume of runoff water flowing through each section. Ditches running over the landfill should have low base slope to minimize erosion (note: recommended maximum slope is 10%). Even though short-term maintenance is expected, long-term maintenance of drainage ditches cannot be ensured.

Artificial channels are usually designed with sections of regular geometric shapes. Table 9.1 lists six geometric shapes that are in common use. The trapezoid is the most common shape for channels with unlined earth banks, for it provides side slopes for stability (Van Te Chow, 1959).

Table 9.1. Geometric elements for channel sections (Van Te Chow, 1959)

Section	Area A	Wetted perimeter P	Hydraulic radius R	Top width T
 Rectangle	by	$b + 2y$	$\frac{by}{b + 2y}$	b
 Trapezoid	$(b + zy)y$	$b + 2y\sqrt{1 + z^2}$	$\frac{(b + zy)y}{b + 2y\sqrt{1 + z^2}}$	$b + 2zy$
 Triangle	zy^2	$2y\sqrt{1 + z^2}$	$\frac{zy}{2\sqrt{1 + z^2}}$	$2zy$
 Circle	$\frac{1}{8}(\theta - \sin\theta)d_0^2$	$\frac{1}{2}\theta d_0$	$\frac{1}{4}\left(1 - \frac{\sin\theta}{\theta}\right)d_0$	$(\sin \frac{1}{2}\theta)d_0$ or $2\sqrt{y(d_0 - y)}$
 Parabola	$\frac{2}{3}Ty$	$T + \frac{8}{3}\frac{y^2}{T}$ *	$\frac{2T^2y}{3T^2 + 8y^2}$ *	$\frac{3}{2}\frac{A}{y}$
 Round-cornered rectangle ($y > r$)	$\left(\frac{\pi}{2} - 2\right)r^2 + (b + 2r)y$	$(\pi - 2)r + b + 2y$	$\frac{(\pi/2 - 2)r^2 + (b + 2r)y}{(\pi - 2)r + b + 2y}$	$b + 2r$

A typical drainage swale arrangement is shown in Figure 9.1, and a typical cross section of a primary drainage ditch is shown in Figure 9.2.

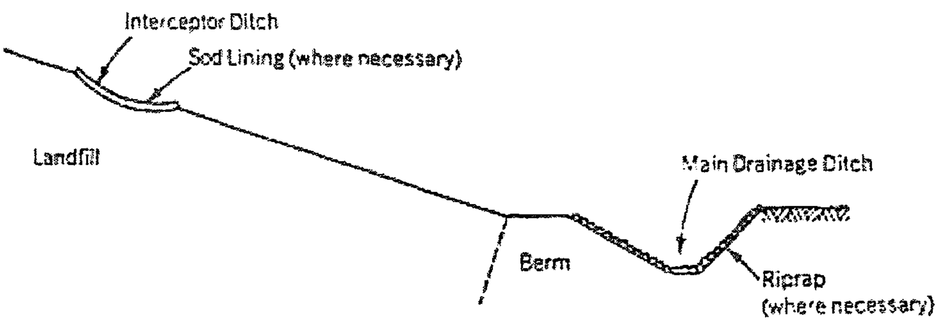


Figure 9.1. Typical arrangements in landfills for surface water routing (Bagchi, 1989)

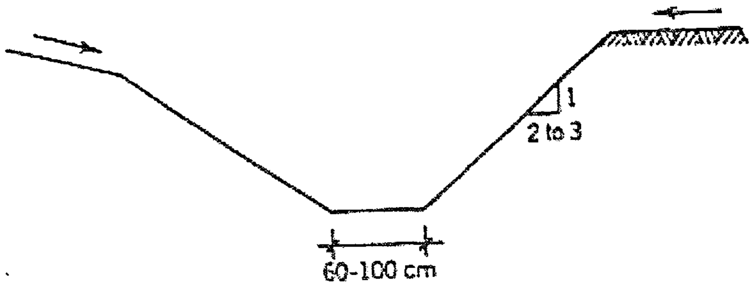


Figure 9.2. Typical cross section of drainage ditch (Bagchi, 1989)

For all drainage design, a trial-and-error method is used to find the dimensions of the section. For most cases a slope of the base is assumed and kept constant throughout the trial-and-error process (Bagchi, 1989).

9.2. Culvert

Circular or rectangular culverts are used to drain water below a road. The culvert inlet and outlet should provide a smooth transition to provide a smooth transition to minimize erosion at entrance and exit points; concrete should be used for entrance and exit. In many instances, maintenance of the culvert in the long term is not envisioned. Therefore, a concrete culvert is preferable over a metal culvert, which needs to be replaced more often. A culvert can flow full or partially full. The flow characteristics depend on inlet geometry, slope, size, roughness, approach, tailwater condition, and so on. Although the use of nomographs is suggested for high design flows, 45 cm to 50 cm circular section culverts with a minimum base slope of 1% can be safely used for flows up to 0.28 m^3/sec (Bagchi, 1989).

In Sinop (Meşedağı) sanitary landfill, the circular shaped culvert was chosen and surface water drainage system was designed. The calculation and design steps are described in Section 9.3.

9.3. Design of Surface Water Ditches and Culverts in Sinop Landfill

9.3.1. Surface Water Ditches

In Sinop (Meşedağı) sanitary landfill. the trapezoid shaped stormwater ditch is designed. As it is mentioned in previous section. a trial-and-error method is used to find the dimensions of the section. The dimensions of the trapezoid shaped stormwater ditch is given below:

z : slope of the ditch (1 / 2.5)
l : bottom width of the ditch. (0.5 m)
h : height of the ditch. (0.35 m)

The first step includes the calculation of the longitudinally slope which is calculated by the dividing the ditch level difference to the ditch length.

Then the surface water flowrate is calculated. The amount of surface water includes the amount of stormwater. Rational Method is used in the flowrate calculation. The basic equation in this method is given below :

$$Q = C \cdot I \cdot A \qquad (9.1)$$

where,

Q : surface water flowrate. l/s
C : surface runoff coefficient
I : average rainfall intensity. l/s/ha (for 2 year, 30 min. rainfalls equals to 82)
A : drainage area. ha

Then. the critical depth is found by using the abacus given in Figure 9.3. The critical depth of water is read from the abacus by matching the N value that is calculated. The critical depth of defines the maximum water level that can be flow through the ditch.

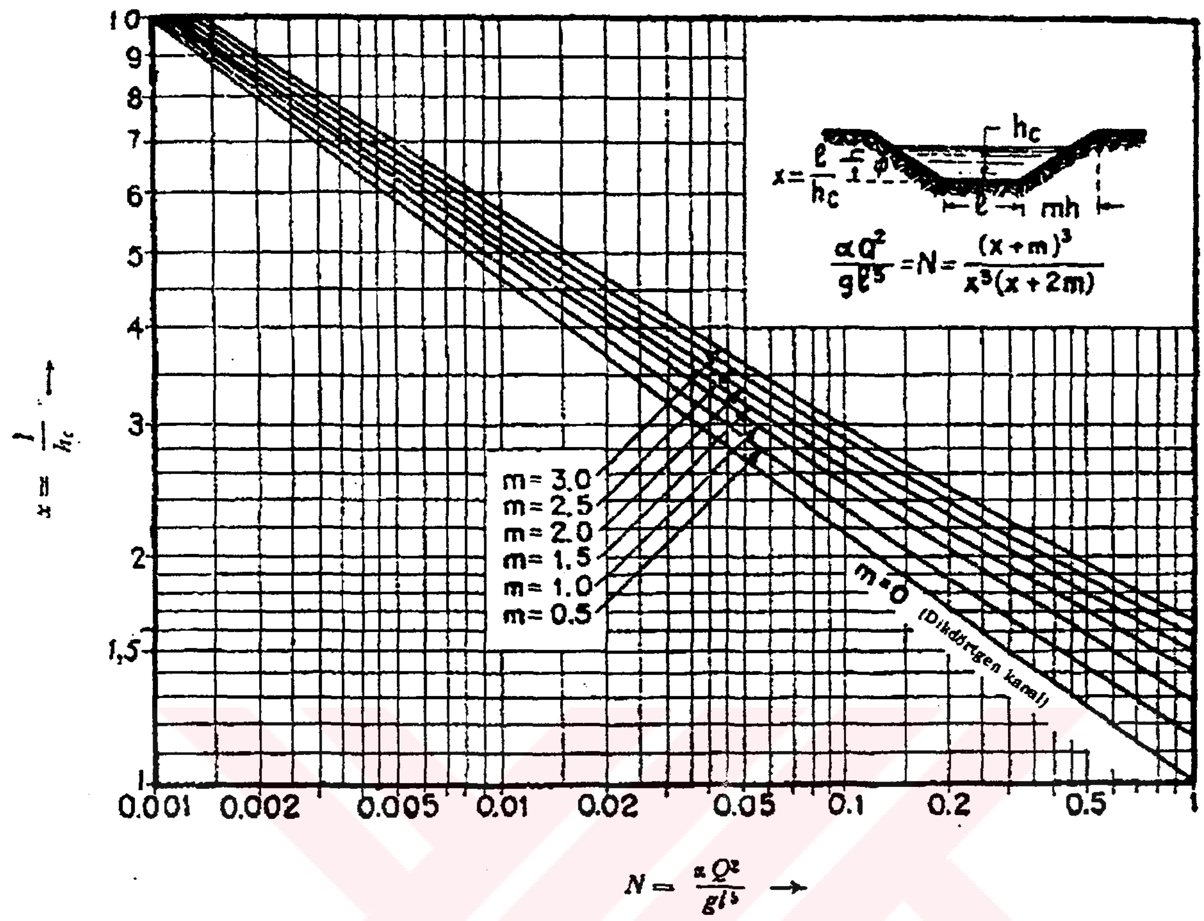


Figure 9.3. Trapezoid shaped channels, determination of critical depth (Lencastre, 1970)

where,

N : the coefficient read from the abacus, $N = (\alpha . Q^2)/(g . l^5)$,

α : Coriolis coefficient (α = 1, Lencastre, 1970),

Q : surface flowrate, m^3/sec

g : gravity acceleration, m/sec^2

l : bottom width of the ditch, m

h_c : the critical depth of water, m

m : the slope of the ditch,

$x = l / h_c$

After the calculation of the critical depth of water, the average depth of water is calculated. In this calculations, the geometric elements table given in Table 9.2 is used.

Table 9.2. Trapezoid shaped channels : geometric elements (Lencastre, 1970)

h/l \ m	0,125	0,25	0,50	0,75	1,0	1,5	2,0	2,5	3,0	4,0
0,05	0,994	0,988	0,976	0,963	0,955	0,935	0,917	0,900	0,885	0,857
10	988	976	955	935	917	885	857	833	813	778
15	982	965	935	908	885	845	813	780	763	727
20	976	955	917	885	857	813	778	750	727	692
25	971	944	900	864	833	786	750	722	700	667
0,30	0,965	0,935	0,885	0,845	0,813	0,763	0,727	0,700	0,679	0,647
35	960	926	870	828	794	744	708	682	661	632
40	955	917	857	813	778	727	692	667	647	619
45	949	908	845	799	763	713	679	654	635	609
50	944	900	833	786	750	700	667	643	625	600
0,6	0,935	0,885	0,813	0,763	0,727	0,679	0,647	0,625	0,609	0,586
7	926	870	794	744	708	661	632	611	596	576
8	917	857	778	727	692	647	619	600	586	568
9	908	845	763	713	679	635	609	591	578	561
1,0	900	833	750	700	667	625	600	583	571	556
1,1	0,892	0,823	0,738	0,689	0,656	0,616	0,593	0,577	0,566	0,551
2	885	813	727	679	647	609	586	571	561	547
3	877	803	717	669	639	602	581	567	557	544
4	870	794	708	661	632	596	576	563	553	541
5	864	785	700	654	625	591	571	559	550	538

where.

h_c : critical water depth .

l : bottom width of the ditch.

m : slope of the ditch (accepted as 2,5; range 2 - 3; see Figure 9.2)

K : coefficient given in the table.

h_m : the average depth of water.

$h_m = K \cdot h$

The area that water flows through is calculated by using the average depth of water with the formula of trapezoid shape shown in Table 9.2.

After all these calculations, the velocity of the surface water that will flow through that ditch is calculated by dividing the surface flow to the area.

All these calculations are shown in Table 9.3.

Table 9.3. Surface water drainage system, calculation table

Ditch No.		Ditch Levels		Ditch Length	Level Difference	Drainage Area	Runoff Coefficient	Rainfall Intensity	Surface Flow	Longitudinally Slope	Ditch Cross-Section		The Average Depth of Water	Critical Depth	Area	Velocity
From	To	Begin.	End	L (m)	H (m)	A (ha)	C	I (l/sec/ha)	Q (m^3/sec)	S (%)	W (m)	H(m)	h_m (m)	h_c (m)	A (m^2)	V (m/sec)
LOT-1																
0+288	0+322	78.39	77.62	34	0,77	0,08	1	82	0.007	0.0226	0.5	0,35	0.010	0.010	0,005	1.32
0+322	0+342	77.62	76.69	20	0.93	0.07	1	82	0.012	0.0465	0.5	0.35	0.040	0.048	0.024	0.51
0+342	0+369	76.69	75.97	27	0.72	0.07	1	82	0.018	0.0267	0.5	0.35	0.041	0.049	0.024	0.74
0+369	0+520	75.97	75.06	151	0,91	1.00	1	82	0.100	0.0060	0,5	0,35	0,094	0.132	0.069	1.44
Discharge Point-1 ; 400 mm culvert																
0+318	0+436	73.86	59.65	118	14,21	0.80	1	82	0.066	0.1204	0.5	0,35	0,075	0.100	0.052	1.27
0+436	0+500	59.65	55.87	64	3.78	0,40	1	82	0.098	0.0591	0.5	0.35	0.096	0.135	0,071	1.38
0+770	0+743	75.12	72.02	27	3.1	0.20	1	82	0,016	0.1148	0.5	0,35	0,041	0.049	0.024	0.67
0+743	0+683	72.02	66.65	60	5.37	0,40	1	82	0.049	0.0895	0.5	0.35	0,066	0.085	0.044	1.12
0+683	0+536	66,65	57,03	147	9,62	0,90	1	82	0.123	0.0654	0.5	0.35	0,101	0.143	0.076	1.63
0+536	0+500	57.03	55.87	36	1.16	0,22	1	82	0.141	0.0322	0,5	0.35	0.122	0.156	0.098	1.44
Discharge Point-2 ; 300 mm culvert																
0+285	0+272	78.38	78.25	13	0,13	0.15	1	82	0.012	0.0100	0.5	0.35	0,010	0.010	0.005	2.34
0+272	0+195	78.25	76,72	77	1,53	0.30	1	82	0.037	0.0199	0.5	0.35	0.054	0,068	0.034	1,07
0+195	0+174	76.72	76.53	21	0.19	0.15	1	82	0,049	0.0090	0.5	0.35	0.066	0.085	0,044	1.12
0+174	0+013	76.53	75.72	161	0.81	1,10	1	82	0.139	0.0050	0.5	0,35	0.106	0.152	0.081	1.72
Discharge Point-3 ; 450 mm culvert																
LOT-2																
0+010	0+077	92.83	86.52	67	6.31	0,30	1	82	0.025	0.0942	0.5	0.35	0.046	0.056	0.028	0.86
0+077	0+177	86.52	79.35	100	7.17	0.60	1	82	0.074	0.0717	0.5	0.35	0.081	0.109	0.057	1.31
0+177	0+228	79.35	76.86	51	2.49	0.30	1	82	0.098	0.0488	0.5	0.35	0.096	0.135	0.071	1.38
0+156	0+000	76.71	75.93	156	0.78	2.60	1	82	0.328	0.0050	0.6	0.50	0.155	0.231	0.153	2.14
0+705	0+761	94.43	91.84	56	2.59	0,20	1	82	0.016	0.0463	0.5	0.35	0.041	0.049	0.024	0.67
0+761	0+821	91.84	86.39	60	5.45	0,60	1	82	0.066	0.0908	0.5	0.35	0.075	0.100	0.052	1.27
0+821	0+895	86.39	77.93	74	8.46	0,70	1	82	0.123	0.1143	0.5	0.35	0.101	0.143	0.076	1.63
Discharge Point-4 ; 250 mm culvert																
0+422	0+371	99.42	97.48	51	1.94	0.11	1	82	0.009	0.0380	0.5	0.35	0.010	0.010	0.005	1.81
0+371	0+347	97.48	95.68	24	1.8	0.06	1	82	0.014	0.0750	0.5	0.35	0.041	0.049	0.024	0.57
0+347	0+326	95.68	94.28	21	1.4	0.05	1	82	0.018	0.0667	0.5	0.35	0.041	0.049	0.024	0.74
Discharge Point-5 ; 150 mm culvert																
0+422	0+431	99.42	99.35	9	0.07	0.20	1	82	0.016	0.0078	0.5	0.35	0.041	0.049	0.024	0.67
0+431	0+485	99.35	98.65	54	0.7	0.50	1	82	0.057	0.0130	0.5	0.35	0.068	0.088	0.045	1.27
0+485	0+605	98.65	96.56	120	2.09	0.90	1	82	0.131	0.0174	0.5	0.35	0.103	0.147	0.078	1.67
0+605	0+703	96.56	94.44	98	2.12	0.70	1	82	0.189	0.0216	0.5	0.35	0.121	0.179	0.098	1.93
Discharge Point-6 ; 400 mm culvert																
LOT-3																
0+142	0+214	88.71	84.10	72	4.61	0.20	1	82	0.016	0.0640	0.5	0.35	0.041	0.049	0.024	0.67
0+214	0+294	84.10	76.75	80	7.35	0.30	1	82	0.041	0.0919	0.5	0.35	0.058	0.074	0.037	1.11
0+287	0+322	78.42	77.61	35	0,81	0,40	1	82	0.033	0.0231	0.5	0.35	0.054	0.068	0.034	0.96
0+322	0+342	77.61	76.68	20	0.93	0.30	1	82	0.057	0.0465	0.5	0.35	0.068	0.088	0.045	1.27
0+342	0+369	76.68	76.03	20	0.65	0.30	1	82	0.082	0.0325	0.5	0.35	0.083	0.114	0.059	1.39
0+369	0+507	76.03	75.20	138	0.83	1.80	1	82	0.230	0.0060	0.5	0.35	0.133	0.200	0.111	2.06
Discharge Point-7 ; 500 mm culvert																
0+004	0+041	88.87	88.46	37	0.41	0.10	1	82	0.008	0.0111	0.5	0.35	0.010	0.010	0.005	1.65
0+041	0+087	88.46	88.24	46	0.22	0.20	1	82	0.025	0.0048	0.5	0.35	0.046	0.056	0.028	0.86
0+087	0+138	88.24	87.98	51	0.26	0.46	1	82	0.062	0.0051	0.5	0.35	0.075	0.100	0.052	1.21
0+246	0+138	90.68	88.56	108	2.12	0.33	1	82	0.027	0.0196	0.5	0.35	0.046	0.056	0.028	0.95
Discharge Point-8 ; 200 mm culvert																
0+287	0+197	78.42	78.00	90	0.42	0.20	1	82	0.016	0.0047	0.5	0.35	0.041	0.049	0.024	0.67
Discharge Point-9 ; 200 mm culvert																

EXAMPLE : In order to explain more about the calculation steps of stormwater ditch dimensions an example for Lot-1 is given below.

Input Data

Ditch No ; from 0+369 to 0+520
Drainage Area(A); 1.0 ha
Ditch Length ; 151 m
Level difference ; 0.91 m.
Rainfall intensity (i); 82 lt/sec/ha
Runoff coefficient (C); 1

Calculation of Ditch Slope on the Ground

The slope is calculated by the dividing the level difference to the ditch length. Then;

Slope = 0.91 / 151 = 0.006

Calculation of Flowrate

The rainfall intensity matching 2 year, 30 min. rainfalls is equal to 82 l/sec/ha. In addition, the runoff coefficient is assumed as 1; that is all the rain falling onto the ground is flowing towards the slope till to the ditches. Consequently, the flowrate is calculated. In flowrate calculations, the addition of the flowrate coming from the upper ditch must be noticed :

$Q = C . I . A$

$Q = 1 . 82$ l/sec/ha . 1.0 ha + 0.18 m^3/sec = 0.100 m^3/sec.

Calculation of Critical Depth of Water

The critical depth is found by using the abacus given in Figure 9.3. First of all N value is calculated :

$$N = \left(\frac{\alpha . Q^2}{g . l^5} \right)$$

N = (1 . 0.100^2) / (9.81 . 0.5^5) = 0.0326

Then, the x value is found by matching with N=0.0326 and m=2.5. This value equals to about 3.8 and this means;

l / h_c = 3.8, where W=0.5 then h_c = 0.132 m.

Calculation of Average Depth of Water

The average depth of water is found by using Table 9.2. By matching h_c/l = 0.263 with m=2.5 we found the coefficient as 0.7176. Then the average depth of water equals to ;

h_m = 0.132 . 0.7176 = 0.094 m.

Calculation of Area

The area symbolizes the area that water flows through. This are is calculated with the formula shown in Table 9.2. However, the average depth of the water is used in the calculation. Then ;

A = (0.5 + 2.5 . 0.094) . 0.094 = 0.069 m^2

Calculation of Velocity

The area defines the velocity that water flows through and this value should not exceed 3 m/sec. Then the velocity equals to;

V = Q / A = 0.098 / 0.069 = 1.44 m/sec.

The calculations and the results for each lot are given in Tables 9.3.

9.3.2. Culvert

In the calculation of the culvert dimensions, Manning's formula is used. The following formula, known as Manning's formula, is used to design a channel section (Bagchi, 1989) :

$$V = \left(\frac{1}{n}\right).R^{2/3}.J^{1/2} \tag{9.2}$$

$$Q = V.A \tag{9.3}$$

then,

$$Q = \frac{1}{n}.R^{2/3}.J^{1/2}.A \tag{9.4}$$

where,

V : the mean velocity of water, m/sec

R : the mean hydraulic radius ($D/4$ in circular pipes), m

J : slope of the energy line

n : the roughness coefficient

A : Area of the circular pipe section ($\pi . D^2 / 4$), m^2

then,

$$Q = \frac{1}{n}.\left(\frac{D}{4}\right)^{2/3}.J^{1/2}.\left(\frac{\pi.D^2}{4}\right) \tag{9.5}$$

The greatest difficulty in applying the Manning formula is to choose the proper value of n_r. The recommended values of n_r for concrete culverts is 0.016 (Lencastre. 1970).

Calculation of the culvert sections are given below.

Discharge Point-1

Q = 0.100 m^3/sec
n = 0.016
J = 0.0060

$$0.100 = \frac{1}{0.016}.\left(\frac{D}{4}\right)^{2/3}.0.0060^{1/2}.\left(\frac{\pi.D^2}{4}\right)$$ D = 0.36 m then, D ≅ 400 mm.

Discharge Point-2

Q = 0.141 m^3/sec
n = 0.016
J = 0.0322

$$0.141 = \frac{1}{0.016}.\left(\frac{D}{4}\right)^{2/3}.0.0322^{1/2}.\left(\frac{\pi.D^2}{4}\right)$$ D = 0.30 m then, D = 300 mm.

Discharge Point-3

Q = 0.139 m^3/sec

n = 0.016

J = 0.0050

$$0.139 = \frac{1}{0.016}.\left(\frac{D}{4}\right)^{2/3}.0.0050^{1/2}.\left(\frac{\pi . D^2}{4}\right)$$ D = 0.42 m then, D ≅ 450 mm.

Discharge Point-4

Q = 0.123 m^3/sec

n = 0.016

J = 0.1143

$$0.123 = \frac{1}{0.016}.\left(\frac{D}{4}\right)^{2/3}.0.1143^{1/2}.\left(\frac{\pi . D^2}{4}\right)$$ D = 0.22 m then, D ≅ 250 mm.

Discharge Point-5

Q = 0.018 m^3/sec

n = 0.016

J = 0.0667

$$0.018 = \frac{1}{0.016}.\left(\frac{D}{4}\right)^{2/3}.0.0667^{1/2}.\left(\frac{\pi . D^2}{4}\right)$$ D = 0.12 m then, D ≅ 150 mm.

Discharge Point-6

Q = 0.189 m^3/sec

n = 0.016

J = 0.0216

$$0.189 = \frac{1}{0.016}.\left(\frac{D}{4}\right)^{2/3}.0.0216^{1/2}.\left(\frac{\pi.D^2}{4}\right) \qquad D = 0.36\text{ m} \quad \text{then,} \quad D \cong 400\text{ mm.}$$

Discharge Point-7

Q = 0.230 m^3/sec

n = 0.016

J = 0.0060

$$0.230 = \frac{1}{0.016}.\left(\frac{D}{4}\right)^{2/3}.0.0060^{1/2}.\left(\frac{\pi.D^2}{4}\right) \qquad D = 0.49\text{ m} \quad \text{then,} \quad D \cong 500\text{ mm.}$$

Discharge Point-8

Q = 0.027 m^3/sec

n = 0.016

J = 0.0196

$$0.027 = \frac{1}{0.016}.\left(\frac{D}{4}\right)^{2/3}.0.0196^{1/2}.\left(\frac{\pi.D^2}{4}\right) \qquad D = 0.18\text{ m} \quad \text{then,} \quad D \cong 200\text{ mm.}$$

Discharge Point-9

Q = 0.016 m^3/sec

n = 0.016

J = 0.0047

$$0.016 = \frac{1}{0.016}.\left(\frac{D}{4}\right)^{2/3}.0.0047^{1/2}.\left(\frac{\pi.D^2}{4}\right) \qquad D = 0.19\text{ m} \quad \text{then,} \quad D \cong 200\text{ mm.}$$

The surface water drainage system is shown in Figure 9.4.

Figure 9.4. General view of surface water drainage system

10. DESIGN OF GAS VENTING SYSTEM

Landfill gas management systems should be part of the infrastructure and will normally be subject to waste management systems to ;

- minimize the risk of migration or accumulation off –site,
- eliminate so far as possible the risk of explosion or asphyxiation,
- prevent unacceptable risk to human health, detriment to the environment or nuisance.

10.1. Generation of Landfill Gases

The generation of landfill gas is the result of the decomposition of the organic matter present in substantial percentages in municipal solid waste, under anaerobic conditions which occur usually soon after filling the refuse under sanitary landfilling methods. If allowed to migrate in an uncontrolled manner from a landfill, it may enter in the buildings near the site. Uncontrolled release of the gas to the atmosphere may cause air pollution. The typical landfill gasses found in landfills include CH_4, CO_2, N_2, O_2, H_2, NH_3, H_2S, CO and trace constituents. However, methane and carbon dioxide are the principal components of landfill gas. When methane is present in the air in concentrations between 5 and 15 percent, it is explosive. However, methane can destroy vegetation by displacing oxygen from the root zone. Therefore, landfill gas control is needed to prevent any unwanted situations. (Tchobanoglous et al., 1993).

Typical landfill gas composition is given in Table 10.1.

Table 10.1. Typical landfill gas composition (Tchobanoglous et al., 1993)

Component	Percent (dry volume basis)
Methane	45 - 60
Carbon dioxide	40 - 60
Nitrogen	2-5
Oxygen	0.1 - 1.0
Sulfides, disulfides, mercaptants, etc.	0 - 1.0
Ammonia	0.1 - 1.0
Hydrogen	0 - 0.2
Carbon monoxide	0 - 0.2
Trace constituents	0.01 - 0.6

The generation of the principal landfill gases is thought to occur in five more or less sequential phases as given in Figure 10.1. Each of these phases is described below (Tchobanoglous et al., 1993).

Phase 1, Initial Adjustment ; is the phase in which the organic biodegradable components in MSW undergo microbial decomposition as they are placed in a landfill and soon after . In Phase 1, biological decomposition occurs under aerobic conditions, because a certain amount of air is trapped within the landfill (Tchobanoglous et al., 1993).

Phase 2, Transition Phase ; is the phase in which oxygen is depleted and anaerobic conditions begin to develop. As the landfill becomes anaerobic, nitrate and sulfate, which can serve as electron acceptors in biological conversion reactions, are often reduced to nitrogen gas and hydrogen sulfide. The pH of leachate, if any is formed, starts to drop due to the presence of organic acids and the effect of the elevated concentrations of CO_2 within the landfill (Tchobanoglous et al., 1993).

Phase 3, Acid Phase ; is the phase in which the microbial activity initiated in Phase 2 accelerates with the production of significant amounts of organic acids and lesser amounts of hydrogen gas. The first step in three-step process involves the enzymemediated transformation (hydrolysis) of higher molecular mass compounds into compounds suitable for use by microorganisms as a source of energy and cell carbon. The second step in the process (acidogenesis) involves the microbial conversion of the compounds resulting from the first step into lower-molecular mass intermediate compounds as typified by acetic acid (CH_3COOH) and small concentrations of fulvic and more complex organic acids. Carbon dioxide (CO_2) is the principal gas generated during Phase 3. Smaller amounts of hydrogen gas (H_2) will also be produced. The microorganism in this conversion, described collectively as nonmethanogenic, consist of facultative and obligate anaerobic bacteria. These microorganisms are often identified as acidogens or acid formers (Tchobanoglous et al., 1993).

Phase 4, Methane Fermentation Phase ; is the phase in which a second group of microorganisms, which convert the acetic acid and hydrogen gas formed by the acid formers in the acid phase to CH_4 and CO_2, becomes predominant. In some cases, these organisms will begin to develop toward the end of Phase 3. The microorganisms responsible for this conversion are strict anaerobes and are called methanogens. Collectively, they are identified in the literature as methanogens or methane formers. In Phase 4, both methane and acid formation proceed simultaneously, although the rate of acid formation is considerably reduced.

Because the acids and the hydrogen gas produced by the acid formers have been converted to CH_4 and CO_2 in Phase 4, the pH within the landfill will rise to more neutral values in the range of 6.8 to 8. In turn, the pH of the leachate, if formed, will rise, and the concentration of BOD_5 and COD and the conductivity of the leachate will be reduced. With higher pH values, fewer inorganic constituents can remain in solution; as a result, the concentration of heavy metals present in the leachate will also be reduced (Tchobanoglous et al., 1993).

Phase 5, Maturation Phase ; is the phase that occurs after the readily available biodegradable organic material has been converted to CH_4 and CO_2 in Phase 4. As moisture continues to migrate through the waste, portions of the biodegradable material that were previously unavailable, will be converted. The rate of landfill gas generation diminishes significantly in Phase 5, because most of the available nutrients have been removed with the leachate during the previous phases and the substrates that remain in the landfill are slowly biodegradable. The principal landfill gases evolved in Phase 5 are CH_4 and CO_2. Depending on the landfill closure measures, small amounts of nitrogen and oxygen may also be found in the landfill gas. During maturation phase, the leachate will often contain humic and fulvic acid, which are difficult to process further biologically (Tchobanoglous et al., 1993).

The variation in gas composition and leachate characteristics with time is given in Figure 10.1

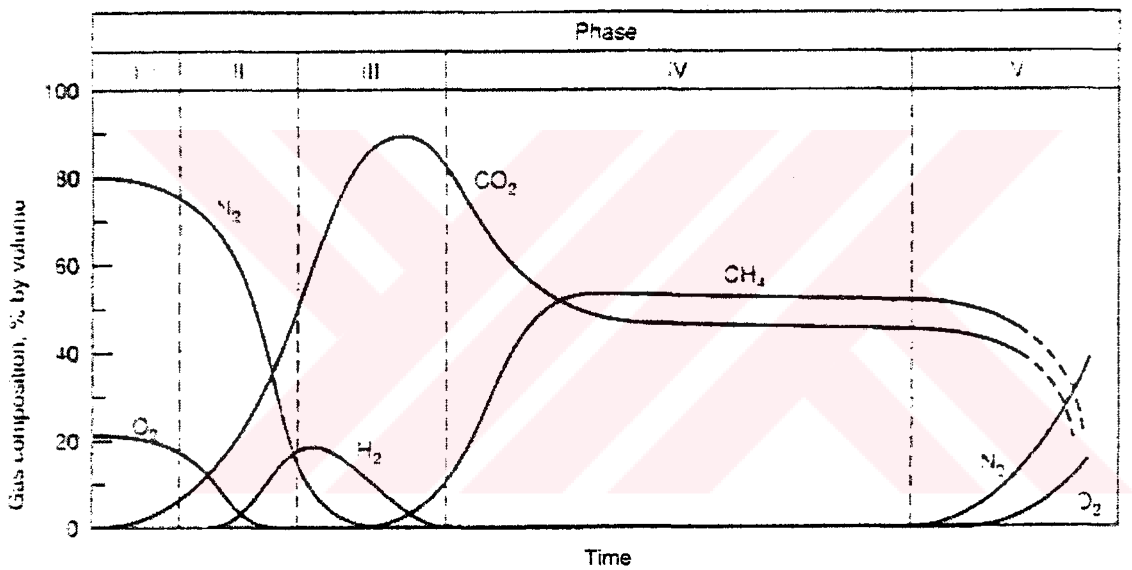


Figure 10.1. Variation in gas composition and characteristics with time (Tchobanoglous et al., 1993)

10.1.1. Method I – Calculation of Landfill Gas Production by Chemical Formula

In general, the organic materials present in solid wastes can be divided into two classifications; (1) those materials that will decompose rapidly (three months to five years) and (2) those materials that will decompose slowly (up to 50 years or more) (Tchobanoglous et al., 1993). The rapidly and slowly decomposable organic fraction of MSW are identified in Table 10.2.

Table 10.2. Rapidly and slowly biodegradable organic constituents in municipal solid wastes (Tchobanoglous et al., 1993)

Organic Waste Component	Rapidly Biodegradable	Slowly Biodegradable
Food Wastes	√	
Newspaper	√	
Office Paper	√	
Cardboard	√	
Plastics [(a)]		
Textiles		√
Rubber		√
Leather		√
Yard Wastes	√[(b)]	√[(c)]
Wood		√
Misc. Organics		√

(a) Plastics are generally considered nonbiodegradable.
(b) Leaves and grass trimmings. Typically, 60% of the yard wastes are considered rapidly biodegradable.
(c) Woody portions of yard wastes.

In order to estimate the chemical composition and the amount of gas that can be derived from the biodegradable portion of the MSW, Table 10.3 is set up to determine the percentage distribution of the major elements composting the waste. The moisture content of the waste constituents is taken from Table 5.2.

Table 10.3. Percentage distribution of the rapidly and slowly decomposable organic constituents in Sinop municipal solid wastes (Ergun et al., 1997)

Component	Wet Weight,kg	Dry Weight,kg	C	H	O	N	S	Ash
		Rapidly Decomposable Organic Constituents						
Food Wastes	54.19	16.26	7.80	1.04	6.11	0.42	0.07	0.81
Paper	9.66	9.08	3.94	0.48	4.02	0.03	0.02	0.55
Total	*63.85*	*25.34*	*11.74*	*1.52*	*10.13*	*0.45*	*0.09*	*1.36*
		Slowly Decomposable Organic Constituents						
Textiles	7.20	6.48	3.11	0.42	2.59	0.14	0.0013	0.21
Wood	0.46	0.37	0.18	0.02	0.16	0	0	0.01
Misc. Organics	0.41	0.35	0.09	0.01	0.01	0	0	0.24
Total	*8.07*	*7.20*	*3.38*	*0.45*	*2.76*	*0.14*	*0.013*	*0.46*

The molar composition of the elements neglecting the ash was computed in Table 10.4.

Table 10.4. Molar composition of the elements in Sinop municipal solid wastes

	Elements				
	C	H	O	N	S
gr/mole	12	1	16	14	32
Total Moles					
Rapidly decomposable	0.978	1,152	0.633	0.032	0.0028
Slowly decomposable	0.282	0.450	0.173	0.010	0.0004

Data on molecular weight, density and specific weight of gases found in sanitary landfill is given in Table 10.5.

Table 10.5. Molecular weight, density and specific weight of gases found in sanitary landfill at standard conditions (0°C, 1 atm) (Tchobanoglous et al., 1993)

Gas	Formula	Molecular Weight,g	Density, g/l	Specific Weight, kg/m^3
Air		28	1.2928	1.294
Ammonia	NH_3	17	0.7708	0.772
Carbon dioxide	CO_2	44	1.9768	1.978
Carbon monoxide	CO	28	1.2501	1.251
Hydrogen	H_2	2	0.0898	0.090
Hydrogen sulfide	H_2S	34	1.5392	1.539
Methane	CH_4	16	0.7167	0.718
Nitrogen	N_2	28	1.2507	1.252
Oxygen	O_2	32	1.4289	1.429

The chemical formula of rapidly and slowly decomposable organic constituents are:

- Rapidly decomposable organic constituents = $C_{31}H_{47}O_{20}N$
- Slowly decomposable organic constituents = $C_{28}H_{45}O_{17}N$

Amount of gas that can be derived from the rapidly and slowly decomposable organic constituents :

- Rapidly decomposable

$$C_{31}H_{47}O_{20}N + 10H_2O \rightarrow 16CH_4 + 15CO_2 + NH_3 \qquad (10.1)$$

753 g   180 g   256 g   660 g   17g

- Slowly decomposable

$$C_{28}H_{45}O_{17}N + 11H_2O \rightarrow 14CH_4 + 14CO_2 + NH_3 \qquad (10.2)$$

667 g   198 g   224 g   616 g   17 g

Volume of methane and carbon dioxide produced from 1 mole of rapidly and slowly decomposable organic constituents:

- Rapidly Decomposable

$$\text{Methane} = \frac{256\,x\,25.34}{753\,x\,0.718} = 12\ m^3 \text{ at standard conditions}$$

$$\text{Carbon dioxide} = \frac{660\,x\,25.34}{753\,x\,1.978} = 11.23\ m^3 \text{ at standard conditions}$$

- Slowly Decomposable

$$\text{Methane} = \frac{224\,x\,7.20}{667\,x\,0.718} = 3.37\ m^3 \text{ at standard conditions}$$

$$\text{Carbon dioxide} = \frac{616\,x\,7.20}{667\,x\,1.978} = 3.36\ m^3 \text{ at standard conditions}$$

Total theoretical amount of gas generated per unit dry weight of organic matter destroyed:

- Rapidly Decomposable
  (12 m^3 + 11.23 m^3) / 25.34 kg = 0.917 m^3 gas / kg RBW

- Slowly Decomposable
  (3.37 m^3 + 3.36 m^3) / 7.20 kg = 0.935 m^3 gas / kg SBW

It is assumed that 75% of the rapidly biodegradable and 50% of the slowly biodegradable organic waste is available for degradation. The reason is that some organic waste materials in plastic bags are not degraded and some of the material are too dry to support biological activity. Then ;

The fraction of the total waste that is rapidly and slowly biodegradable ;

- Rapidly Biodegradable : 0.2534 x 0.75 = 0.190 kg RBW / kg total waste
- Slowly Biodegradable : 0.0720 x 0.50 = 0.036 kg SBW / kg total waste

Total amount of gas produced per kg of solid waste ;

- Rapidly Biodegradable : 0.190 x 0.917 = 0.174 m^3 gas / kg total solid waste
- Slowly Biodegradable : 0.036 x 0.935 = 0.034 m^3 gas / kg total solid waste

Variation in Gas Production with Time

Under normal conditions, the rate of decomposition, as measured by gas production, reaches a peak within the first two years and then slowly tapers off, continuing in many cases for periods up to 25 years or more. If moisture is not added to the wastes in a well-compacted landfill, it is not uncommon to find materials in their original form years after they were buried (Tchobanoglous et al., 1993).

The variation in the rate of gas production from the anaerobic composition of the rapidly (five years or less-some highly biodegradable wastes are decomposed within days of being placed in a landfill) and slowly (5 to 50 years) bidegradable organic materials in MSW can be modeled as shown in Figure 10.2. As shown in Figure 10.2, the yearly rates of decomposition for rapidly and slowly decomposable material are based on a triangular gas production model in which the peak rate of gas production occurs one and five years. after gas production starts. Gas production is assumed to start at the end of the first full year of landfill operation. The area under the triangle is equal to one half of the base times the altitude, therefore, the total amount of gas produced from the waste placed the first year of operation is equal to (Tchobanoglous et al., 1993);

$$= 1/2 \text{ (base, yr) x (altitude, peak rate of gas production, } m^3/\text{kg.y)}$$

Using a triangular gas production model, the total rate of gas production from a landfill in which wastes were placed for a period of five years is obtained graphically by summing the gas produced from the rapidly and slowly bidegredable portions of the MSW deposited each year. The total amount of gas produced corresponds to the area under the rate curve (Tchobanoglous et al., 1993).

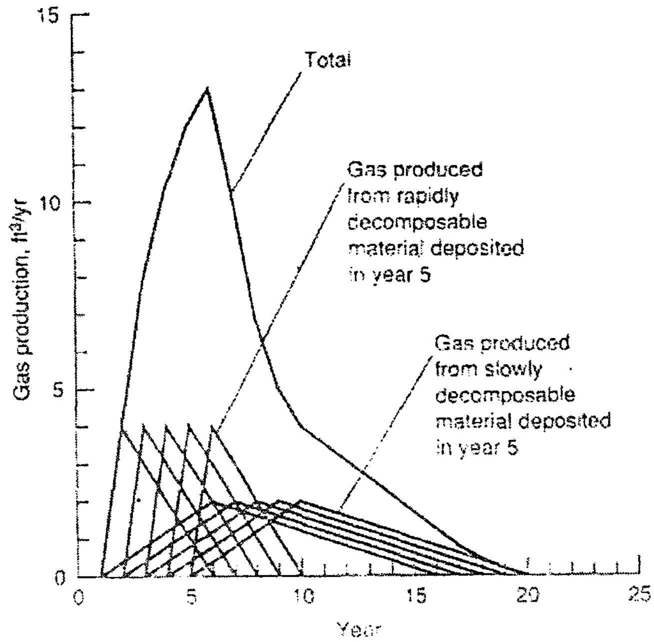


Figure 10.2. Graphical representation of gas production over a five-year period from the rapidly and slowly decomposable organic materials placed in a landfill (Tchobanoglous et al., 1993)

The variation in the rate of gas production from the anaerobic composition of the rapidly and slowly bidegredable organic materials in MSW can be modeled as shown in Figure 10.3 and Figure 10.4.

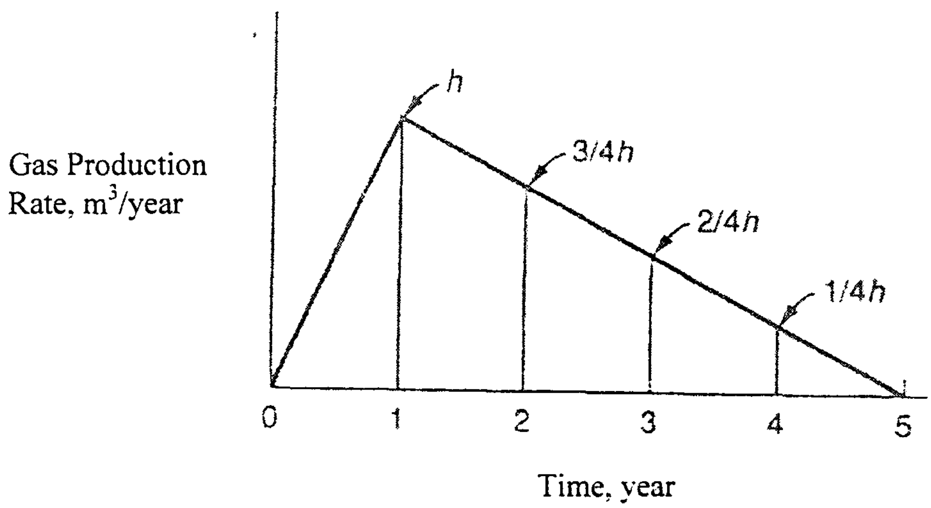
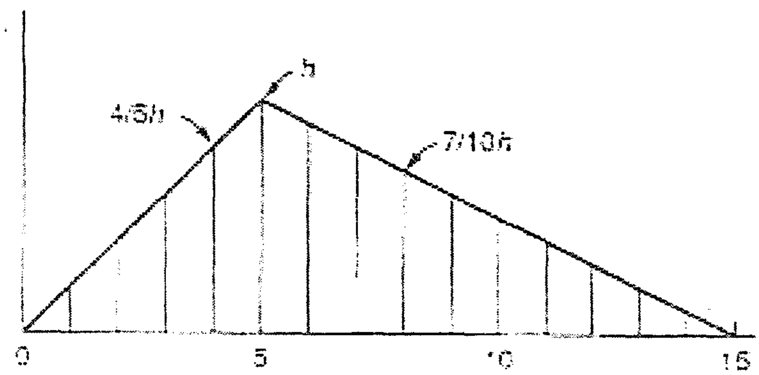


Figure 10.3. The gas production over the 5-year period (Tchobanoglous et al.. 1993)

Gas Production
Rate, m^3/year



Time. year

Figure 10.4. The gas production over the 15-year period (Tchobanoglous et al.. 1993)

Because the area of the triangle is equal to one half the base times the altitude, the total amount of gas produced is equal to ;

= 1/2 (base, yr) x (altitude. peak rate of gas production. m^3/yr)

To explain more about the calculation steps of gas generation, an example for year 2000 is given below.

Example : Calculation of Gas Generation from Solid Wastes Deposited in Year 2000

As it is mentioned in previous pages, the total amount of gas produced per kg of solid waste is;

- Rapidly Biodegradable = 0.174 m^3 gas / kg total solid waste
- Slowly Biodegradable = 0.034 m^3 gas / kg total solid waste

The total amount of gas produced for the total amount of MSW in year 2000 was calculated.

- Rapidly Biodeg. = 0.174 m^3 gas / kg MSW x 15 707 t. MSW x 10^3 kg/t = 2 733 018 m^3
- Slowly Biodeg. = 0.034 m^3 gas / kg MSW x 15 707 t. MSW x 10^3 kg/t = 534 038 m^3

The peak rate of gas production was calculated as below ;

The total amount of gas produced = 1/2 (base, yr) x (h, peak rate of gas production, m^3/yr)

- Rapidly Biodegradable

  2 733 018 m^3 = 1/2 (5 yr) x (h, peak rate of gas production, m^3/yr), h_R = 1 093 236 m^3/yr

- Slowly Biodegradable

  534 038 m^3 = 1/2 (15 yr) x (h, peak rate of gas production, m^3/yr), h_S = 71 207 m^3/yr

The gas generation for the future years is calculated by using the peak rates and the triangles given in Figure 10.2 and 10.3. The calculations are given below.

Year 2001 = (h_R / 2) + (h_S / 10) = (1093236 / 2) + (71207 / 10) = 553739 m^3
Year 2002 = (7h_R / 8) + (3h_S / 10) = (7 x 1093236 / 8) + (71207 / 10) = 977 949 m^3
Year 2003 = (5h_R / 8) + (5h_S / 10) = (5 x 1093236 / 8) + (5 x 71207 / 10) = 718 876 m^3
Year 2004 = (3h_R / 8) + (7h_S / 10) = (3 x 1093236 / 8) + (7 x 71207 / 10) = 459808 m^3
Year 2005 = (h_R / 8) + (9h_S / 10) = (1093236 / 8) + (9 x 71207 / 10) = 200741 m^3
Year 2006 = (19h_S / 20) = (19 x 71207 / 20) = 67 647 m^3
Year 2007 = (17h_S / 20) = (17 x 71207 / 20) = 60 526 m^3
Year 2008 = (15h_S / 20) = (15 x 71207 / 20) = 53 405 m^3
Year 2009 = (13h_S / 20) = (13 x 71207 / 20) = 46 285 m^3
Year 2010 = (11h_S / 20) = (11 x 71207 / 20) = 39 164 m^3
Year 2011 = (9h_S / 20) = (9 x 71207 / 20) = 32 043 m^3
Year 2012 = (7h_S / 20) = (7 x 71207 / 20) = 24 922 m^3
Year 2013 = (5h_S / 20) = (5 x 71207 / 20) = 17 802 m^3
Year 2014 = (3h_S / 20) = (3 x 71207 / 20) = 10 681 m^3
Year 2015 = (h_S / 20) = (71207 / 20) = 3 560 m^3

The same calculation steps are implemented for the other years between 2000-2030, and the annual gas generation for the project is given in Table 10.6 and shown in Figure 10.5. The total gas generation from each lot is given in Table 10.7.

Table 10.6. Annual gas generation from total landfill area (m^3) (Method I)

Year	Total MSW tonnes/year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
2000	15 707	0	553 739	977 044	718 876	459 808	200 741	67 647	60 526	53 405	46 285	39 164	32 043	24 922	17 802	10 681	3 560	0	0	0	0	0	0	0	0	0	0
2001	16 140	0	0	568 992	1 004 883	738 679	472 475	206 271	69 510	62 193	54 876	47 560	40 243	32 926	25 609	18 292	10 975	3 658	0	0	0	0	0	0	0	0	0
2002	16 586	0	0	0	584 707	1 032 636	759 080	485 523	211 967	71 430	63 911	56 392	48 873	41 354	33 835	26 316	18 797	11 278	3 759	0	0	0	0	0	0	0	0
2003	17 045	0	0	0	0	600 897	1 061 228	780 098	498 967	217 836	73 408	65 680	57 953	50 226	42 499	34 772	27 045	19 318	11 591	3 864	0	0	0	0	0	0	0
2004	17 518	0	0	0	0	0	617 577	1 090 687	801 753	512 818	223 883	75 445	67 504	59 562	51 620	43 679	35 737	27 796	19 854	11 912	3 971	0	0	0	0	0	0
2005	18 006	0	0	0	0	0	0	634 764	1 121 040	824 065	527 089	230 114	77 545	69 382	61 220	53 057	44 894	36 732	28 569	20 407	12 244	4 081	0	0	0	0	0
2006	18 508	0	0	0	0	0	0	0	652 473	1 152 316	847 055	541 795	236 534	79 708	71 318	62 928	54 537	46 147	37 757	29 366	20 976	12 586	4 195	0	0	0	0
2007	19 026	0	0	0	0	0	0	0	0	670 721	1 184 543	870 745	556 947	243 149	81 938	73 313	64 688	56 063	47 438	38 813	30 188	21 563	12 938	4 313	0	0	0
2008	19 559	0	0	0	0	0	0	0	0	0	689 526	1 217 753	895 158	572 562	249 966	84 235	75 368	66 501	57 634	48 768	39 901	31 034	22 167	13 300	4 433	0	0
2009	20 109	0	0	0	0	0	0	0	0	0	0	708 904	1 251 977	920 315	588 653	256 991	86 602	77 486	68 370	59 254	50 138	41 022	31 906	22 790	13 674	4 558	0
2010	20 675	0	0	0	0	0	0	0	0	0	0	0	728 874	1 287 246	946 241	605 236	264 231	89 042	79 669	70 296	60 923	51 550	42 178	32 805	23 432	14 059	4 686
2011	21 259	0	0	0	0	0	0	0	0	0	0	0	0	749 456	1 323 595	972 961	622 326	271 692	91 556	81 919	72 281	62 644	53 006	43 369	33 731	24 094	14 456
2012	21 861	0	0	0	0	0	0	0	0	0	0	0	0	0	770 669	1 361 058	1 000 499	639 941	279 382	94 147	84 237	74 327	64 417	54 506	44 596	34 686	24 776
2013	22 481	0	0	0	0	0	0	0	0	0	0	0	0	0	0	792 532	1 399 670	1 028 883	658 095	287 308	96 818	86 627	76 436	66 244	56 053	45 861	35 670
2014	23 120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	815 067	1 439 469	1 058 138	676 808	295 477	99 571	89 090	78 609	68 128	57 647	47 165
2015	23 779	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	838 295	1 480 492	1 088 294	696 096	303 898	102 409	91 629	80 849	70 069	59 289
2016	24 458	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	862 239	1 522 778	1 119 378	715 978	312 578	105 334	94 246	83 158	72 071
2017	25 158	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	886 921	1 566 368	1 151 421	736 473	321 526	108 349	96 944	85 539
2018	25 880	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	912 365	1 611 304	1 184 452	757 601	330 749	111 458	99 725
2019	26 624	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	938 595	1 657 628	1 218 505	779 382	340 258	114 662
2020	27 391	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	965 637	1 705 386	1 253 611	801 836	350 062
2021	28 182	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	993 516	1 754 623	1 289 835	824 986
2022	28 998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 022 260	1 805 386	1 327 120
2023	29 838	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 051 396	1 857 726
2024	30 705	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 082 453
2025	31 599	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
2026	32 520	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2027	33 471	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2028	34 450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2029	35 461	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2030	36 503	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Gas Generation		0	553 739	1 546 936	2 308 466	2 832 020	3 111 100	3 264 989	3 416 236	3 564 785	3 710 576	3 853 552	3 993 651	4 130 810	4 264 965	4 396 050	4 523 998	4 652 300	4 784 543	4 920 853	5 061 361	5 206 200	5 355 509	5 509 432	5 668 117	5 831 715	6 000 386

Year	Total MSW tonnes/year	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
2000	15 707	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	16 140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	16 586	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	17 045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	17 518	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	18 006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	18 508	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	19 026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	19 559	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	20 109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	20 675	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	21 259	4 819	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	21 861	14 865	4 955	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	22 481	25 479	15 287	5 096	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2014	23 120	36 684	26 203	15 722	5 241	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2015	23 779	48 510	37 730	26 950	16 170	5 390	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2016	24 458	60 983	49 895	38 807	27 719	16 632	5 544	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2017	25 158	74 134	62 729	51 323	39 918	28 513	17 108	5 703	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2018	25 880	87 993	76 260	64 528	52 796	41 063	29 331	17 599	5 866	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2019	26 624	102 592	90 523	78 453	66 383	54 314	42 244	30 174	18 105	6 035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2020	27 391	117 965	105 548	93 131	80 713	68 296	55 878	43 461	31 044	18 626	6 209	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2021	28 182	360 168	121 371	108 595	95 819	83 043	70 268	57 492	44 716	31 940	19 164	6 388	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2022	28 998	848 854	370 588	124 883	111 737	98 592	85 446	72 301	59 155	46 009	32 864	19 718	6 573	0	0	0	0	0	0	0	0	0	0	0	0	0
2023	29 838	1 365 594	873 463	381 332	128 503	114 976	101 450	87 923	74 397	60 870	47 343	33 817	20 290	6 763	0	0	0	0	0	0	0	0	0	0	0	0
2024	30 705	1 911 691	1 405 264	898 837	392 410	132 236	118 316	104 397	90 477	76 558	62 638	48 719	34 799	20 879	6 960	0	0	0	0	0	0	0	0	0	0	0
2025	31 599	1 113 960	1 967 336	1 446 168	925 000	403 831	136 085	121 760	107 436	93 111	78 786	64 461	50 137	35 812	21 487	7 162	0	0	0	0	0	0	0	0	0	0
2026	32 520	0	1 146 448	2 024 712	1 488 345	951 977	415 609	140 054	125 311	110 569	95 826	81 084	66 341	51 599	36 856	22 114	7 371	0	0	0	0	0	0	0	0	0
2027	33 471	0	0	1 179 949	2 083 877	1 531 836	979 795	427 754	144 147	128 973	113 800	98 627	83 453	68 280	53 107	37 933	22 760	7 587	0	0	0	0	0	0	0	0
2028	34 450	0	0	0	1 214 495	2 144 888	1 576 684	1 008 481	440 277	148 367	132 749	117 132	101 514	85 897	70 279	54 661	39 044	23 426	7 809	0	0	0	0	0	0	0
2029	35 461	0	0	0	0	1 250 120	2 207 804	1 622 933	1 038 063	453 192	152 719	136 643	120 568	104 492	88 416	72 341	56 265	40 189	24 114	8 038	0	0	0	0	0	0
2030	36 503	0	0	0	0	0	1 286 858	2 272 686	1 670 627	1 068 569	466 510	157 207	140 659	124 111	107 563	91 015	74 466	57 918	41 370	24 822	8 274	0	0	0	0	0
Total Gas Production		6 174 292	6 353 600	6 528 485	6 729 126	6 925 707	7 128 420	6 012 717	3 849 620	2 242 818	1 208 609	763 795	624 333	497 832	384 668	285 226	199 906	129 120	73 293	32 860	8 274	0	0	0	0	0

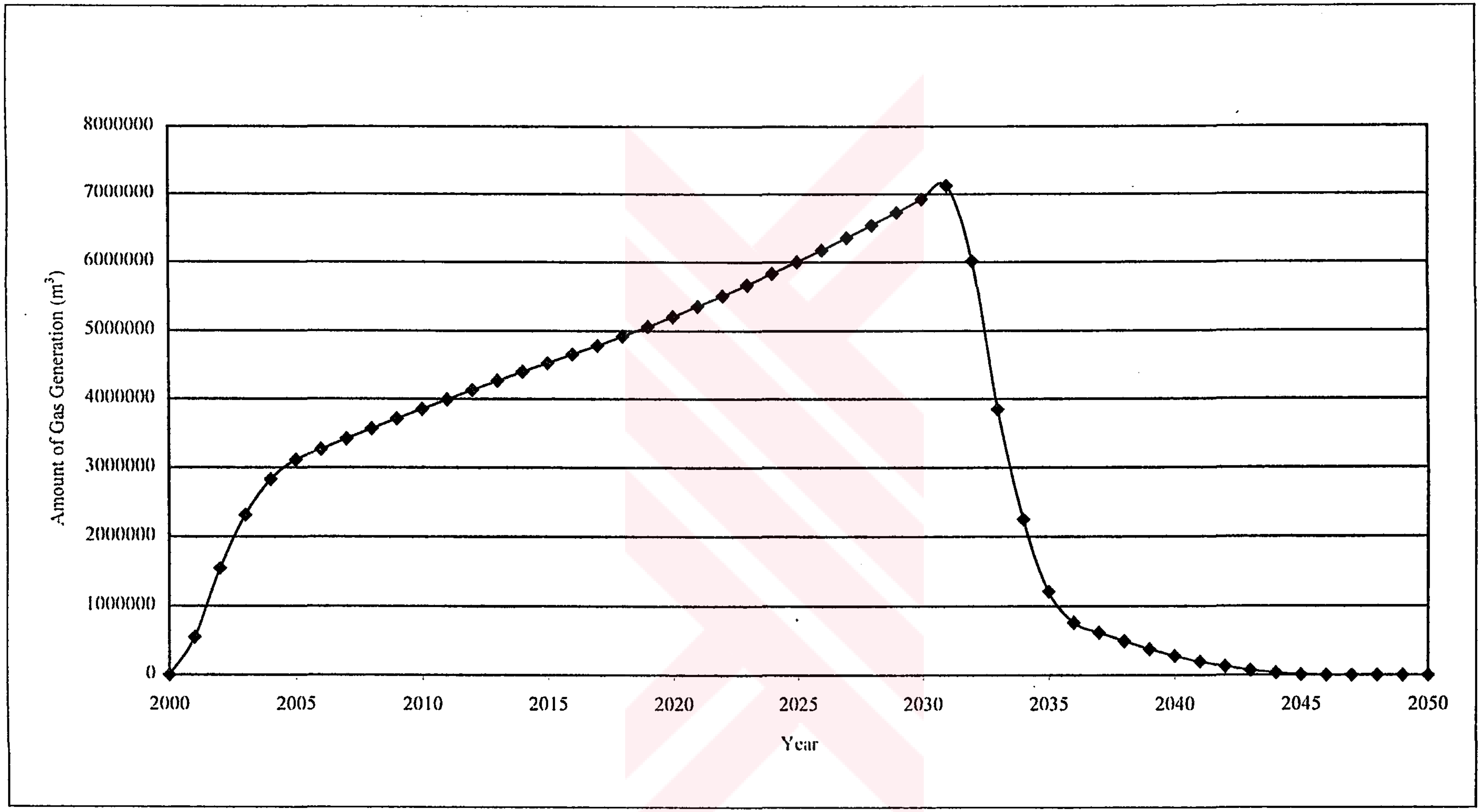


Figure 10.5. Method I - Annaul gas generation (m^3)

Table 10.7. Total Gas Generation from Lot-1, Lot-2 and Lot-3 (Method I)

	Lot-1	**Lot-2**	**Lot-3**
Total Gas Generation (m^3)	64,767,104	71,723,635	22,134,253

10.1.2. Method II – LandGEM Model

The Landfill Gas Emissions Model (LandGEM) provides an automated estimation tool for quantifying air emissions from municipal solid waste (MSW) landfills. The model was developed by the Control Technology Center (CTC) of the U.S. Environmental Protection Agency (Thorneloe et al., 1998).

Air emissions from landfills come from landfill gas, generated by the decomposition of refuse in the landfill. Landfill gas is assumed by this model to be roughly half methane and half carbon dioxide, with additional, relatively low concentrations of other air pollutants. The following information is needed to estimate emissions from a landfill (Thorneloe et al., 1998):

- The design capacity of the landfill,
- The amount of refuse in place in the landfill, or the annual refuse acceptance rate for the landfill,
- The methane generation rate (k),
- The potential methane generation capacity (Lo),
- The concentration of total nonmethane organic compounds (NMOC) and speciated NMOC found in the landfill gas,
- The years the landfill has been in operation,
- Whether the landfill has been used for disposal of hazardous waste (codisposal).

The estimation method used by the model is a simple first-order decay equation. Because the data available for landfills, such as data on the quantity, age, and composition of the refuse in the landfill are limited utilization of a more sophisticated calculation method was not justified. The Landfill Gas Emissions Model estimates emissions of methane, carbon dioxide, nonmethane organic compounds, and selected air pollutants (Thorneloe et al., 1998).

The Landfill Gas Emissions Model can be used with site-specific data for all the information needed to generate emission estimates, or it can be used with two different sets of default values. One set of default values (the CAA defaults) is for estimating emissions to determine the applicability of the Clean Air Act (CAA) regulations for MSW landfill emissions, specifically the New Source Performance Standards (NSPS) for new MSW Landfills and the emission guidelines for existing MSW landfills (Thorneloe et al., 1998).

The CAA default values in the model provide emission estimates that would reflect the expected maximum emissions and generally would be used only for determining the applicability of the regulations to a landfill. To estimate actual emissions in the absence of site-specific data, a second set of default values (the *AP-42* defaults) is provided in the model. The *AP-42* default values in the model are based on emission factors from the U.S. Environmental Protection Agency's *Compilation of Air Pollutant Emission Factors*, *AP-42* (EPA, 1997a). The *AP-42* default values provide emission estimates that should reflect typical landfill emissions and are the values suggested for use in developing estimates for state inventories (Thorneloe et al., 1998).

The EPA fully recognizes that modeling landfill air emissions accurately is difficult due to limitations in available information for inputs to the model. However, as new landfills are constructed and operated and better information is collected, the present modeling approach can be improved. As better data become available, including longer term data on landfill air emissions, better modeling approaches are expected to evolve [16].

The Landfill Gas Emissions Model can be operated in a Windows 3.1, Windows 3.11, or Windows 95 environment. The program is designed to model and store multiple landfill studies. Within a landfill study, reports and graphs of the estimated emissions can be produced for any particular air pollutant. The model provides the following features (Thorneloe et al., 1998):

- Emission rate estimates for methane, NMOC, and selected air pollutants emitted from solid waste landfills, annually over the life of the landfill and for a specified number of years after the landfill has closed;
- Two different sets of model default values for calculating emissions: a set of default values for determining the applicability of the NSPS or emission guidelines (the CAA defaults) for MSW landfills and a set of default values based on emission factors from *AP-42* (the *AP-42* defaults).
- Estimates for the year of closure for a landfill based on the landfill capacity and refuse acceptance rate;
- Reports of emissions by pollutant over the life of the landfill for a given landfill, which can be printed; and
- Graphs of emissions by pollutant over the life of the landfill for a given landfill, which can be printed (Thorneloe et al., 1998).

In Sinop project, the Landfill Gas Emissions Model is applied with two different sets of default values; the CAA defaults and the AP-42 defaults.

10.1.2.1. Calculation with CAA Defaults: The CAA default values in the model provide emission estimates that would reflect the expected maximum emissions and generally would be used only for determining the applicability of the regulations to a landfill (Thorneloe et al., 1998). The input model and landfill parameters to process the model are given for each lot in Table 10.8.

Table 10.8. Input Model and Landfill Parameters for the Calculation of Gas Generation with CAA Defaults in LandGEM Model

LOT-1	
Model Parameters	**Landfill Parameters**
Lo : 170.00 m3 k : 0.0500 1/yr NMOC : 4000.00 ppmv Methane : 50 % volume Carbon Dioxide : 50 % volume	Landfill Type : No Co-Disposal Year Opened : 2000 Closure Year : 2015 Capacity : 386524 Mg
LOT-2	
Model Parameters	**Landfill Parameters**
Lo : 170.00 m3 k : 0.0500 1/yr NMOC : 4000.00 ppmv Methane : 50 % volume Carbon Dioxide : 50 % volume	Landfill Type : No Co-Disposal Year Opened : 2016 Closure Year : 2028 Capacity : 495389 Mg
LOT-3	
Model Parameters	**Landfill Parameters**
Lo : 170.00 m3 k : 0.0500 1/yr NMOC : 4000.00 ppmv Methane : 50 % volume Carbon Dioxide : 50 % volume	Landfill Type : No Co-Disposal Year Opened : 2028 Closure Year : 2030 Capacity : 143017 Mg

The model results for Lot-1. Lot-2 and Lot-3 are given in Figure 10.6. 10.7 and 10.8. respectively.

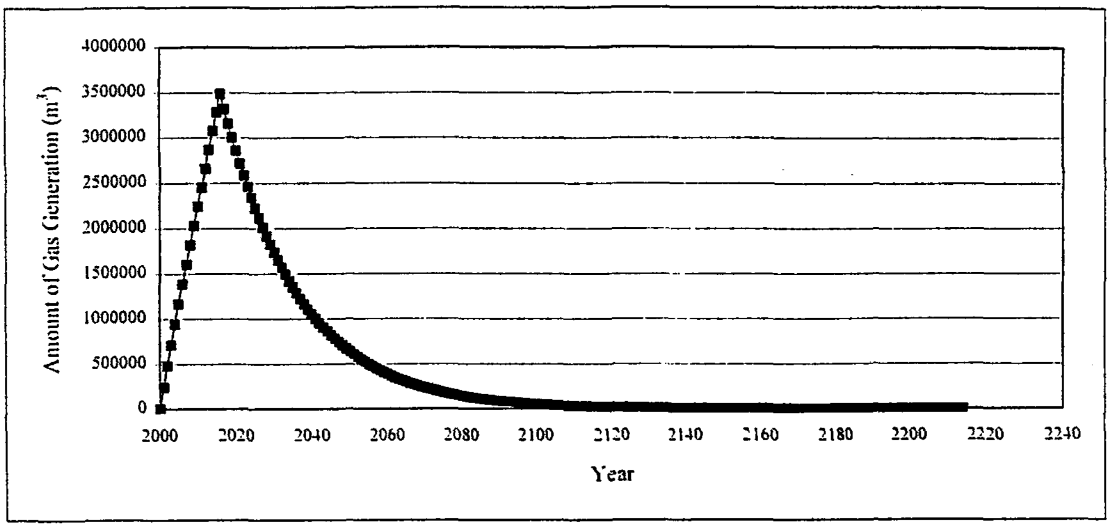


Figure 10.6. Gas generation in Lot-1 (LandGEM model - CAA defaults)

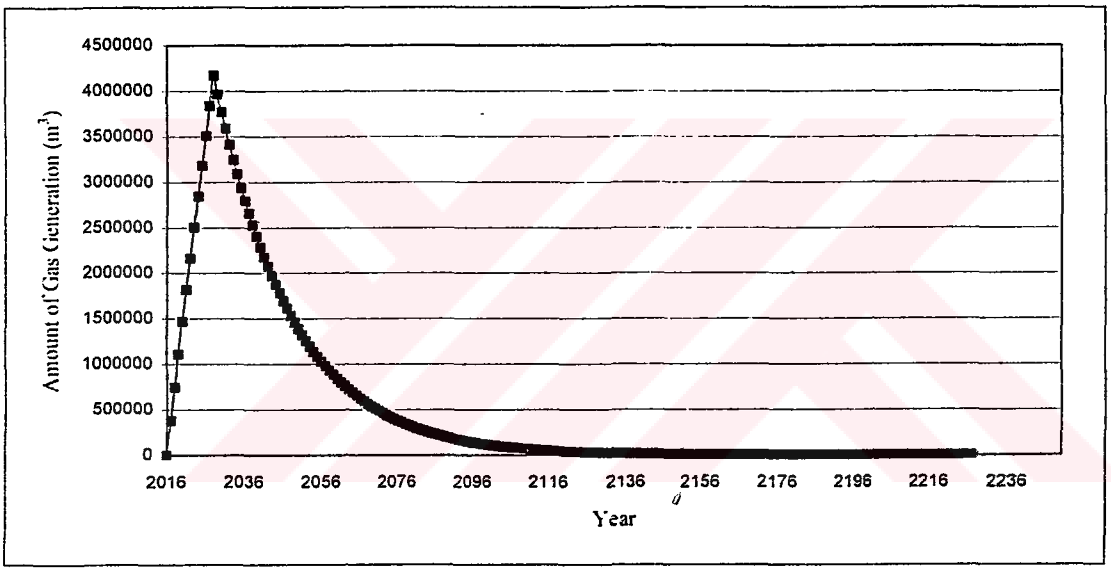


Figure 10.7. Gas generation in Lot-2 (LandGEM model - CAA defaults)

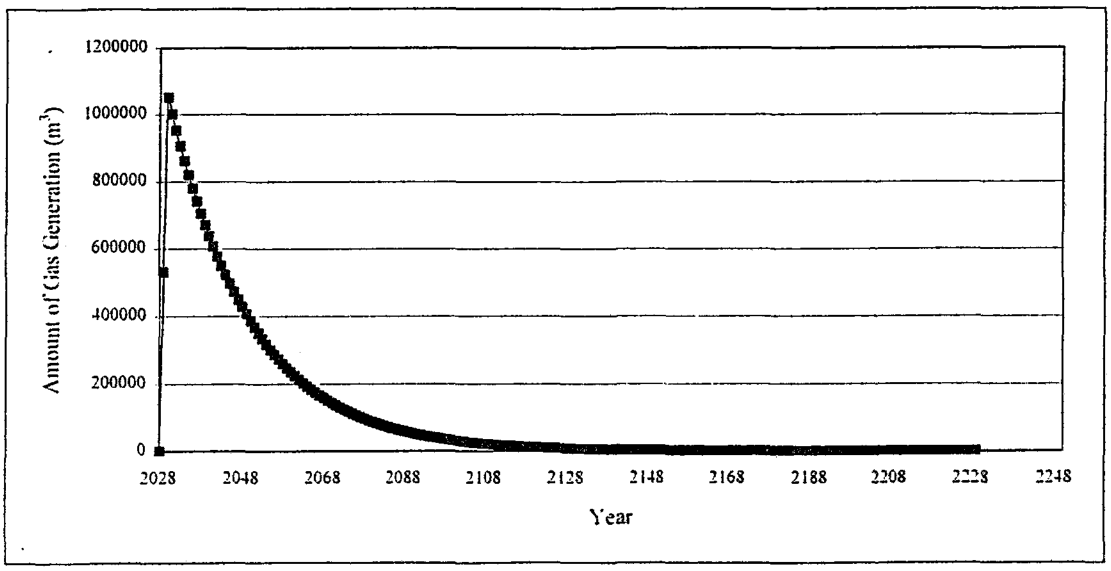


Figure 10.8. Gas generation in Lot-3 (LandGEM model - CAA defaults)

10.1.2.2. Calculation with AP-42 Defaults : The AP-42 default values in the model are based on emission factors from the U.S. Environmental Protection Agency's *Compilation of Air Pollutant Emission Factors, AP-42* (EPA. 1997a). The *AP-42* default values provide emission estimates that should reflect typical landfill emissions and are the values suggested for use in developing estimates for state inventories (Thorneloe et al., 1998). The input model and landfill parameters to process the model are given for each lot in Table 10.9.

Table 10.9. Input Model and Landfill Parameters for the Calculation of Gas Generation with AP-42 Defaults in LandGEM Model

LOT-1	
Model Parameters	**Landfill Parameters**
Lo : 100.00 m3 k : 0.0400 1/yr NMOC : 595.00 ppmv Methane : 50 % volume Carbon Dioxide : 50 % volume	Landfill Type : No Co-Disposal Year Opened : 2000 Closure Year : 2015 Capacity : 386524 Mg
LOT-2	
Model Parameters	**Landfill Parameters**
Lo : 100.00 m3 k : 0.0400 1/yr NMOC : 595.00 ppmv Methane : 50 % volume Carbon Dioxide : 50 % volume	Landfill Type : No Co-Disposal Year Opened : 2016 Closure Year : 2028 Capacity : 495389 Mg
LOT-3	
Model Parameters	**Landfill Parameters**
Lo : 100.00 m3 k : 0.0400 1/yr NMOC : 595.00 ppmv Methane : 50 % volume Carbon Dioxide : 50 % volume	Landfill Type : No Co-Disposal Year Opened : 2028 Closure Year : 2030 Capacity : 143017 Mg

The model results for Lot-1, Lot-2 and Lot-3 are given in Figure 10.9, 10.10 and 10.11, respectively.

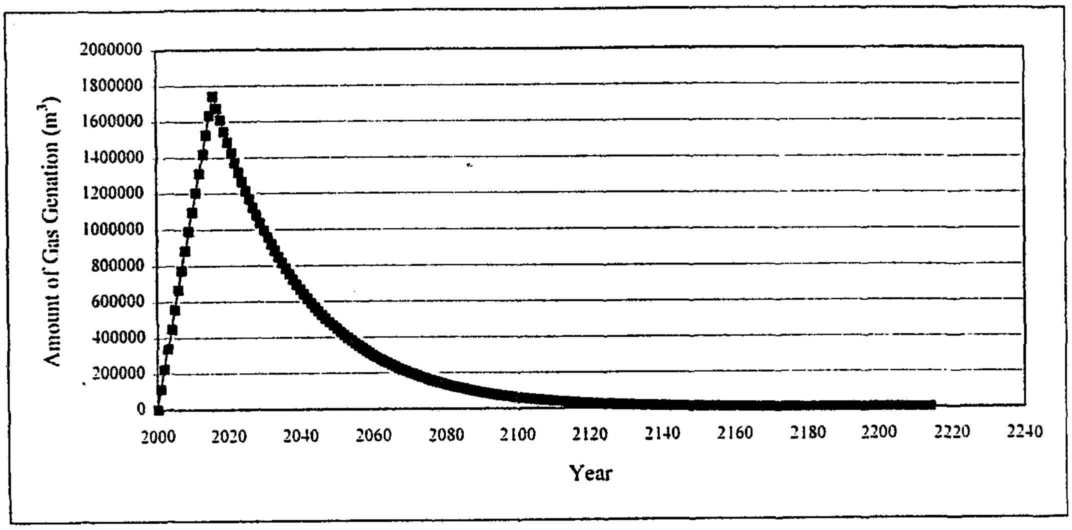


Figure 10.9. Gas generation in Lot-1 (LandGEM Model - AP42 defaults)

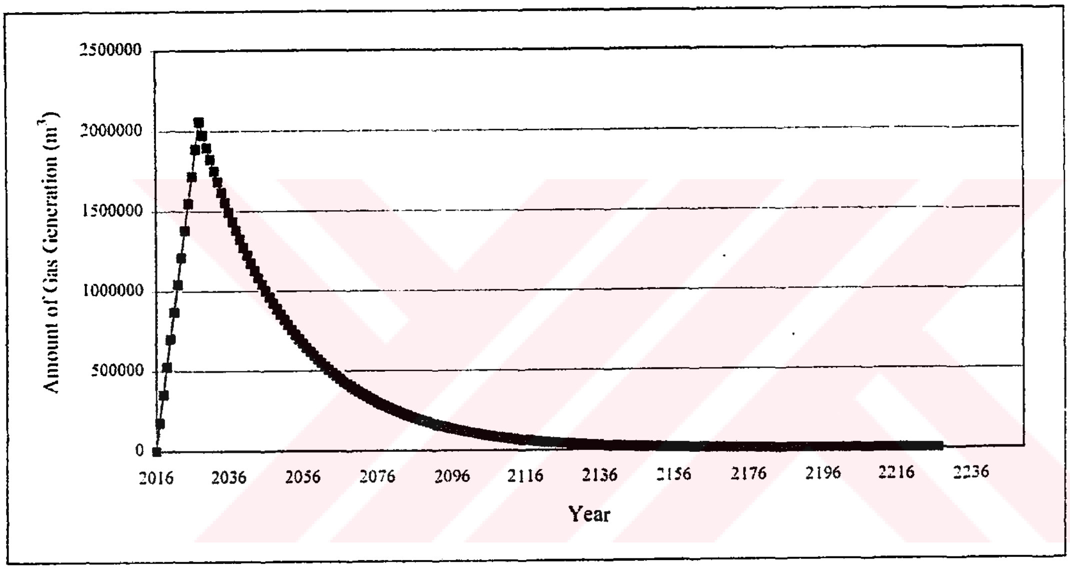


Figure 10.10. Gas generation in Lot-2 (LandGEM Model - AP42 defaults)

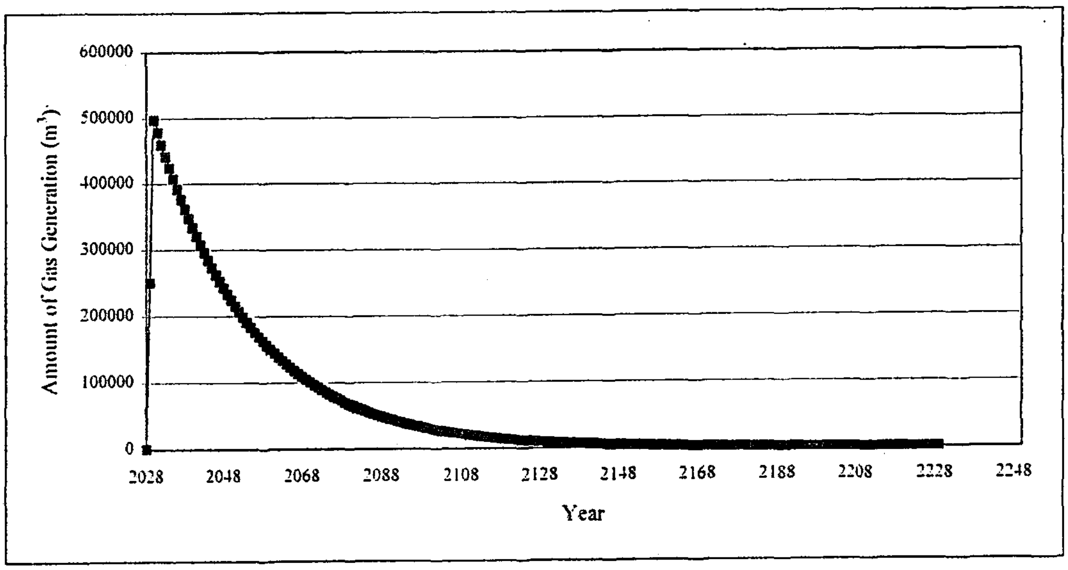


Figure 10.11. Gas generation in Lot-3 (LandGEM Model - AP42 defaults)

10.2. Evaluation of Results of Method I and Method II

Table 10.10. The Overall Summary of Total Gas Generation Calculated by Method I and Method II (m^3)

		LOT-1	LOT-2	LOT-3	TOTAL
Method I		64,767,104	71,723,635	22,134,253	**158,624,992**
LandGEM Model	**AP-42**	57,616,588	63,806,010	12,935,360	**134,357,958**
	CAA	98,462,198	109,030,787	22,105,731	**229,598,716**

Evaluating the table, it is seen that LandGEM model gives two different results according to (i) calculation with AP-42 defaults, and (ii) calculation with AP-42 defaults. As we mentioned before, the CAA default values in the model provide emission estimates that would reflect the expected maximum emissions, and the *AP-42* default values provide emission estimates that should reflect typical landfill emissions and are the values suggested for use in developing estimates for state inventories. The results verify this statement as the calculation of total gas generation with CAA and AP-42 give an amount of 229,598,716 m^3 and 134,357,958 m^3. On the other hand, calculation by chemical formula (Method I) gives the average values. Taking into account the model results, Method I should be preferred for landfill gas generation despite the extra effort needed to simulate the results and it gives the average results.

10.3. Gas Venting System

The movement of landfill gases is controlled to reduce atmospheric emissions, to minimize the release of odorous emissions, to minimize subsurface gas migration, and to allow for the recovery of energy from methane. Gas control systems can be classified as passive or active (Tchobanoglous et al., 1993).

The following issues need to be considered for choosing one system or the other (Bagchi, 1989):

1. Landfill design: chances of gas migration are higher from natural attenuation type landfills than from containment type landfills.
2. Type of soil surrounding the landfill: gas migration can occur more easily through sandy soil than through clayey soil.
3. Distance of usable closed space (homes, warehouses, etc.) near the landfill. Landfill gas can migrate 150 m or more. Any usable closed space within 300 m of a landfill should be monitored for methane gas concentration.
4. Possibility of future use of the landfill.
5. Regulatory mandate: the regulatory agency may mandate the type of gas venting system to be used in a landfill.
6. Waste type: gas generation depends on waste type.

10.3.1. Passive Venting System

Such systems are installed where gas generation is low and off-site migration of gas is not expected. Essentially passive venting is suitable for small municipal landfills (40.000 m^3) and for most nonmunicipal containment type landfills. The system may consist of a series of isolated gas vents. Typical detail of an isolated gas vent is shown in Figure 10.12. No design procedure is available to calculate the number of vents required, but one vent per 7500 m^3 of waste is probably sufficient. Sometimes these isolated vents are connected by a perforated pipe embedded in the grading layer (Bagchi, 1989). This is shown in Figure 10.13.

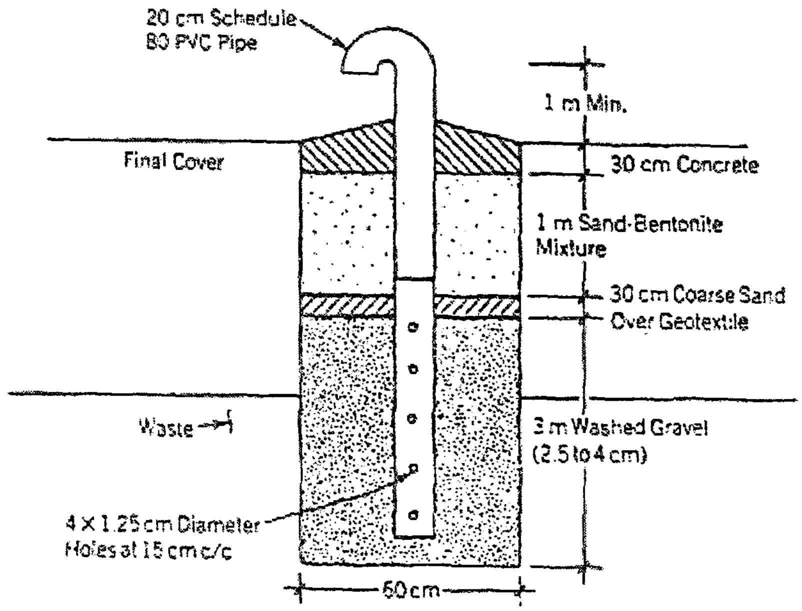


Figure 10.12. Typical detail of an isolated gas vent (Bagchi, 1989)

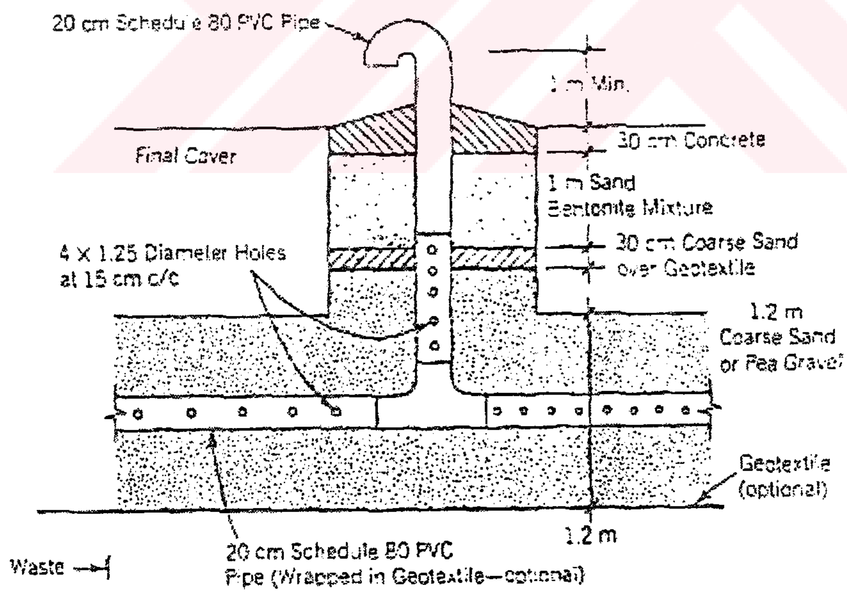


Figure 10.13. Typical detail of a passive gas venting system with a header pipe (Bagchi, 1989)

10.3.2. Active Venting System

An active venting system consists of a series of deep extraction wells connected by a header pipe to a blower that either delivers the gas for energy reuse purposes, or to an on-site burner or simply releases it to the atmosphere. Whether the gas can be released to the atmosphere without burning depends on the following (Bagchi, 1989):

1. Chemical constituents of the gas. If hazardous air contaminants such as vinyl chloride or benzene are present then burning the gas is the preferred option. If such contaminants are absent, releasing the gas to the atmosphere may be acceptable in some (but not all) situations. In addition the regulatory agency should be contacted to determine whether burning landfill gas is mandatory (Bagchi, 1989).

2. Landfill location. If the landfill is located near/within a community then burning is necessary because methane has an odor of its own that may create a nuisance condition (Bagchi, 1989).

- **Extraction Wells**

Spacing of extraction wells is a key issue in extracting landfill gas efficiently. They should be spaced such that their zone of influence overlaps. As shown in Figure 10.14, a 27% overlap can be obtained by installing the extraction wells on the corners of equilateral triangles of side 1.73R and a 100% overlap can be obtained by installing the extraction wells on the corner of regular hexagon of side R. A square array would provide a 60% overlap (Bagchi, 1989).

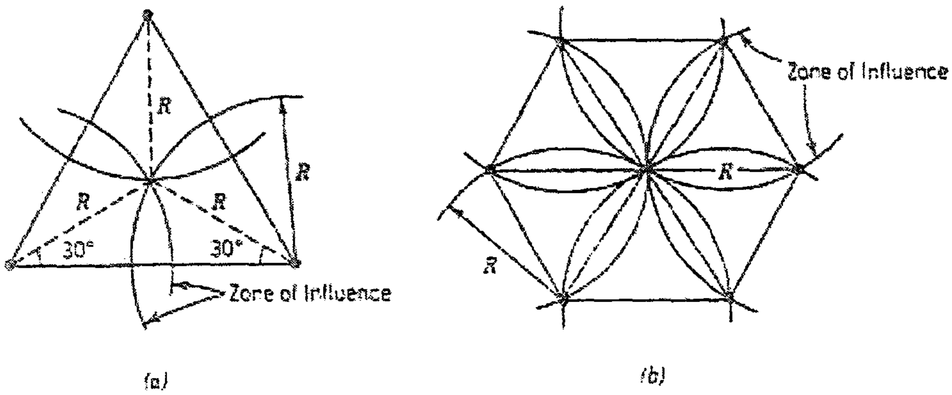


Figure 10.14. Positioning of gas extraction well for complete overlap: (a) triangular array; (b) hexagonal array (Bagchi, 1989)

The zone of a gas extraction system should be determined from actual field study. An extraction well should be installed within the landfill with gas probes at regular distances from the well. The gas extraction well and probe cluster configuration for zone of influence determination is shown in Figure 10.15.

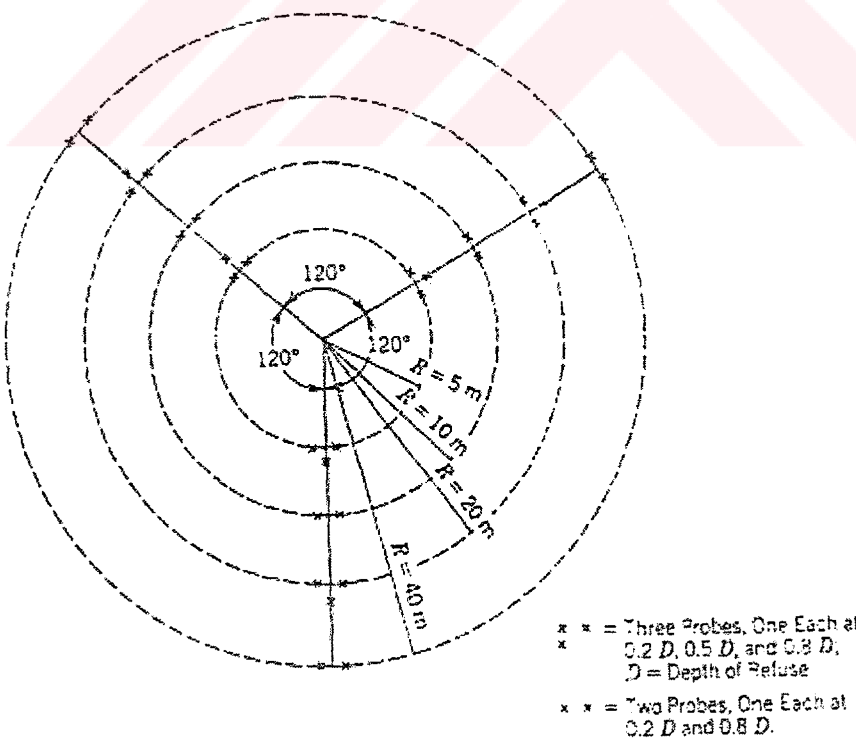


Figure 10.15. Gas extraction well and probe cluster configuration for zone of influence determination (Bagchi, 1989)

Short-term and/or long-term testing is done to design an efficient withdrawal system. Short-term extraction tests usually runs for 48 hours to several days. A short-term test is sufficient where the intension is to design and extraction system to minimize landfill gas migration (Bagchi, 1989).

A long-term test is used to simulate full recovery project conditions. The extraction wells should penetrate 80-90% of the refuse thickness and lower 70-80% of the well should be perforated. The well should be pumped for at least 48 hr and then pressure at all the probes should be monitored for 3 consecutive days. at least twice a day. The probes nearest to the well show highest negative pressure. which drops rapidly with distance. The radius of influence is that radius at which the pressure is nearly zero. In the absence of test data about 40-50 m. radius of influence may be used (Bagchi. 1989).

10.3.3. Design of Gas Venting System for Sinop (Meşedağı) Landfill

In Sinop (Meşedağı) landfill. an active venting system consisting of a series of horizontal and vertical extraction wells connected by a header pipe releasing the gas to the atmosphere after flaring is designed. The main reasons of choosing this system is explained below:

- The wastes in Sinop (Meşedağı) do not include any toxic or hazardous wastes. In this manner, chemical constituents of the gas do not include any hazardous air contaminants. If such contaminants are absent, releasing the gas to the atmosphere may be acceptable.
- Landfill location is far from the community. In this manner, the releasing of the landfill gas, especially methane will not create a nuisance condition because of odor.
- "The Solid Waste Control Regulation" states that the landfill gas should be collected with horizontal and vertical systems and then released to the atmosphere or recovered for energy production.
- The recovery of landfill gas for energy production can be suitable in Sinop. Because 91% of the total wastes are municipal wastes and the organic content is high. However, the investment cost of the energy recovery plant is very high. When the

economic conditions in Turkey is considered, it is not feasible to design a energy recovery plant.

- According to Bagchi's statement mentioned before "in the absence of test data about 40-50 m. radius of influence may be used". The radius of influence (R) is selected as 40 m to be on the secure side. Therefore, the distance between the gas extraction wells is 80 m.
- A common method of treatment of landfill gases is thermal destruction; that is, methane and any other trace gases (including VOCs) are combusted in the presence of oxygen (contained in air) to carbon dioxide (CO_2), sulfur dioxide (SO_2), oxides of nitrogen. and other related gases. The thermal destruction of landfill gases is usually accomplished in a specially designed flaring facility. Because of concerns over air pollution. modern flaring facilities are designed to meet rigorous operating specifications to ensure effective destruction of VOCs and other similar compounds that may be present in the landfill gas (Tchobanoglous. et al., 1993)

As a result of this assumption. the vertical gas wells which be implemented in this project was shown in Figure 10.9.

Gas wells and flare facilities will be equipped together with the disposal process at the same time. While the layers in the landfill rises, the wells will also be equipped towards the ground surface. These wells will be preserved with steel protection around the wells.

The distance between the gas collection wells is about 50 m, and type of the perforated gas collection pipe is HDPE.

The location of the vertical gas wells are shown in Figure 10.10.

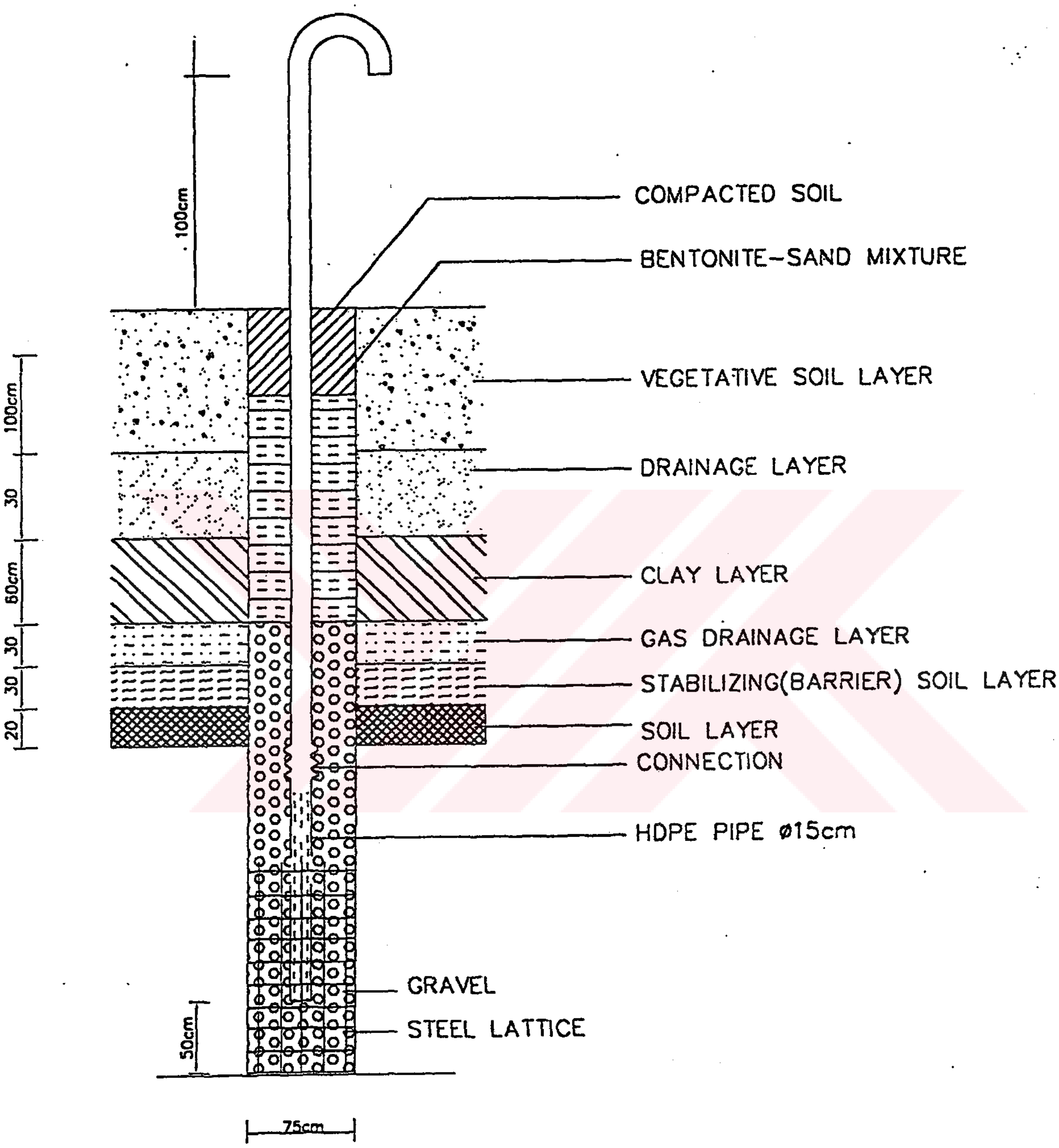


Figure 10.16. Section of vertical gas extraction well

Figure 10.17. General layout of gas extraction wells

11. DESIGN OF LEACHATE TREATMENT PLANT

Landfill leachate initially is a high-strength wastewater, characterized by low pH, high biochemical oxygen demand (BOD), chemical oxygen demand (COD), and by the presence of toxic chemicals. In addition, the leachate quality is variable from landfill to landfill, and over time as a particular landfill ages. Consequently, neither conventional biological waste treatment nor chemical treatment processes separately achieve high removal efficiency over the life of the fill (Quasim, 1994).

Selection and design of a leachate treatment process is not simple. Important factors that govern the selection and design of treatment facilities include leachate characteristics, effluent discharge alternatives, technological alternatives, costs, and permit requirements (Quasim, 1994).

In this section, quality and quantity of leachate to be generated, effluent limits for the treated leachate and treatment processes to be applied are discussed.

11.1. Characteristics of the Leachate

Since both the quantity and quality of leachate show great changes with respect to many factors (e.g. solid waste composition, landfill age, climate), in the design of leachate treatment plants, it is vey important to decide the input data.

Although the treatment facilities are mainly selected by considering the young landfill leachate characteristics, changes to be made in treatment process for old leachate are also discussed.

Many researches have been conducted to identify the characteristics of young landfill leachate. The results of some studies conducted in Turkey and different countries are summarized in Table 11.1.

Table 11.1. Characteristics of young landfill leachates (İnanç et al., 2000)

Parameters	DIFFERENT COUNTRIES			TURKEY		
	Omega Hills U.S.A. (1984)	Serdiana ITALY (1997)	Thessaloniki GREECE (1993)	Harmandalı IZMIR (1996)	Hamitler IZMIR (1996)	Odayeri ISTANBUL (1995-98)
PH	6.0 – 7.6	8.4	5.6 – 6.3	7.5 – 7.8	5.6-8.4	5.6 – 7.5
Alkalinity, mg/l	12.260-15.760	-	-	7.040-13.050	-	11.500-13.150
COD, mg/l	35.800-60.950	12.950	60.000-77.500	14.900-19.980	11.760-32.380	30.100-70.000
BOD_5, mg/l	26.120-45.070	-	31.500-41.000	6.900-11.000	6.450-23.000	21.000-31.000
NH3-N, mg/l	635-1.020	2.760	900-1.510	1.120-2.780	1.400	1.345-2.033
TKN, mg/l	850-1.410	2.800	1.560-2.220	1.350-3.280	-	1.630-4.490
TP, mg/l	0.6-13.8	1.9	14.6-23.8	-	8	1.0-6.0
Chloride, mg/l	2.990-3.620	4.715	3.780-3.820	5.620-6.330	1.210-1.706	-
Fe, mg/l	244-1.710	-	8.7-43.0	14.2-44.0	-	60-130

11.2. Leachate Treatment Problems

Specific problems inherent with treatment of landfill leachate are :

(a) The high strength of waste and magnitude of pollution potential dictates the selection and use of reliable treatment processes.

(b) The changes encountered from landfill to landfill are such that waste treatment techniques applicable at one site may not be directly transferable to other locations. It may be necessary that each instance be separately engineered for proper treatment.

(c) The source of leachate is primarily percolating water that may be seasonal depending on hydrologic and climatic factors.

(d) The chemical nature of the solid wastes accepted at a landfill has a marked effect on the composition of the landfill.

(e) The fluctuations in the leachate quantity and quality, which occur over the both short and long term intervals, must be considered in the treatment plant design. The process designed on efficiently treat the leachates from a young landfill should be modified in the future to treat the leachate adequately as the landfill ages, or effluent standards change (Çakıroğlu, 1998).

11.3. Review of Applicable Wastewater Treatment Processes

Once leachate from a sanitary landfill is collected, numerous alternatives exist for treatment and disposal. The factors determining the type and degree of treatment are :

(1) Leachate characteristics – organic and inorganic concentrations,

(2) Hazardous nature – high concentrations of organic and inorganic toxic chemicals,

(3) Discharge alternatives – surface waters, publicly owned treatment works, land treatment, effluent used on landfill site,

(4) Degree of treatment – leachate characteristics, permit requirement, discharge alternatives,

(5) Treatibility studies – available experimental data, and applicable technologies,

(6) Operational needs – analytical testing, personnel safety training, equipment repairs and maintenance,

(7) Costs – availability of funds, post closure requirements.

Many physical, chemical, biological treatment processes applicable to landfill leachate treatment, along with brief descriptions, are provided in Table 11.2 .

Table 11.2. Physical, chemical, and biological treatment processes applicable to process trains for leachate treatment (Quasim et al., 1994)

Processes	Description
I. PHYSICAL PROCESSES	
A. Equalization	Flow and mass loadings are equalized by means of utilizing in-line or off-line equalization
B. Screening	Suspended and floating debris are removed.
C. Flocculation	Fine particles are aggregated. Gentle stirring is utilized.
D. Sedimentation	Settleable solids and floc are removed by gravity.
E. Flotation	Solids are floated by fine air bubbles and skimmed from the surface.
F. Air Stripping	Air and liquid are contacted in countercurrent flow in a stripping tower. Ammonia, other gases and volatile organics are removed.
G. Filtration	Suspended solids and turbidity are removed in a filter bed or microscreen.
H. Membrane Processes	These are demineralization processes. Dissolved solids are removed by membrane separation. Ultrafiltration, reverse osmosis and electrodialysis are the most common systems.
I. Natural Evaporation	The waste is impounded in basins that have an impervious liner. Liquid is evaporated. The rate of evaporation depends upon temperature, wind velocity, humidity and natural precipitation.
II. CHEMICAL PROCESSES	
A. Coagulation	Colloidal particulates are destabilized by rapid dispersion of chemicals. Organics, suspended solids, phosphorus, some metals, and turbidity are removed. Alum, iron salts and polymers are commonly used coagulation chemicals.
B. Precipitation	Solubility is reduced by chemical reaction. Hardness, phosphorus, and many heavy metals are removed.
C. Gas Transfer	Gases are added or removed by mixing, air diffusion, and change in pressure.
D. Chemical Oxidation	Oxidizing chemicals such as chlorine, ozone, potassium permanganate, hydrogen peroxide and oxygen are used to oxidize organics, hydrogen sulfide, ferrous, and other metal ions. Ammonia and cyanide are oxidized by strong oxidizing chemicals.
E. Chemical Reduction	Metal ions are reduced for precipitation, recovery, and conversion into a less toxic state (chormium). Many metals are also removed. Oxidizing chemicals are reduced (dechlorination). Common reducing chemicals are sulfur dioxide, sodium bisulfite, and ferroussulfate.
F. Disinfection	Destruction of pathogens is achieved by using oxidizing chemicals, or ultraviolet light.
G. Ion Exchange	Removal of inorganic species is achieved from liquid. Ammonia is selectively removed by *clinoptilite* resin. This process is used for demineralization.
H. Carbon Adsorption	Used for reduction of residual BOD, COD, toxic and refractory organics. Some heavy metals are also removed. Carbon is used in powdered form, or in a granular bed.

Table 11.2. Physical, chemical, and biological treatment processes applicable to process trains for leachate treatment (continued).(Quasim et al., 1994)

III. BIOLOGICAL PROCESSES	Microorganisms are cultivated to consume biodegradable organic matter. Biological processes are also used for nitrification and denitrification, and enhanced phosphorus removal.
A. Aerobic	Microorganisms are cultivated in the presence of molecular oxygen. Solids are recirculated. The end product is carbon dioxide.
1. Suspended Growth	The wastewater containing BOD, solids, and nutrients are mixed with a large population of active microorganisms suspended in an aeration basin.
a. Activated Sludge	In the activated sludge process the food and sludge microorganisms are aerated. The microorganisms are settled are recirculated. Common process modifications are conventional, tapered aeration, step aeration, completely mixed, pure oxygen, extended aeration, and contact stabilization.
b. Nitrification	Ammonia nitrogen is oxidized to nitrate. BOD removal can also be achieved in a single aeration basin, or in a separate basin.
c. Aerated Lagoon	Large aeration basins with several days of detention period are used.
d. Sequenching Batch Reactor (SBR)	A SBR is a fill-and-draw activated sludge treatment system. Food and microorganism contact, organic stabilization, sedimentation and discharge of clarified effluent occur in a single basin.
2. Attached Growth	The population of active microorganisms is supported over solid media. The solid media may be of rocks or synthetic material.
a. Trickling Filters	Water is applied over a bed of rocks or synthetic media. Trickling filters are slow rate, high rate, super rate or roughing, and two stage filters. Aeration is by natural draft or forced draft.
b. Rotating Biological Contactor (RBC)	Consists of a serious of closely spaced circular contactor disks of synthetic material. The disks are partly submerged in the wastewater.
c. Combined Suspended and Attached Growth	The system has microorganisms in suspension and attached to a solid media. The process effectively removes BOD, total suspended solids, achieves nitrification. It is extensively used for treatment of high strength industrial waste streams.
B. Anaerobic	The microorganisms are cultivated in the absence of oxygen. The complex organics are solubilized and stabilized. Carbon dioxide, methane and other organic compounds are the end products.
1. Suspended Growth	The waste is mixed with biological solids in a digester, and the contents are commonly stirred, and heated to an optimum temperature.
a. Conventional	High organic strength waste or sludge is stabilized in a digester. The digesters are standard rate, high rate, one-stage, or two-stage.
b. Contact Process	The waste is digested in a completely mixed anaerobic reactor. The digested solids are settled in a clarifier and then returned to the digester.
c. Upflow Anaerobic Sludge Blanket(UASB)	Waste enters the bottom and flows upward through a blanket of biologically formed granules or solids.
d. Denitrification	Nitrite and nitrate are reduced to gaseous nitrogen in an anaerobic environment. A suitable organic carbon source (acetic acid, methanol, sugar, etc.) is required.
e. Combined Anoxic, Anaerobic and Aerobic System	Nitrogen and phosphorus are removed along with BOD in an anoxic, anaerobic and aerobic treatment system. Nitrate is converted to gaseous nitrogen in the anoxic reactor. Phosphorus is released in an anoxic and anaerobic reactors. Uptake of released phosphorus, BOD stabilization, and nitrification of ammonia occurs in the aerobic reactor.

Table 11.2. Physical, chemical, and biological treatment processes applicable to process trains for leachate treatment (continued) (Quasim et al., 1994)

III. BIOLOGICAL PROCESSES (continued)	
2. Attached Growth	The microbiological film is supported over a solid media. The organic matter is stabilized as the waste comes in contact with the attached growth.
a. Anaerobic Filter	The reactor is filled with the solid media, and the waste flows upward. Medium-strength wastes are treated in relatively short hydraulic retention time.
b. Expanded Bed or Fluidized Bed	The reactor is filled with media such as sand, coal, and gravel. The influent and recycled effluent are pumped from the bottom. The bed is kept in an expanded condition. This process has been used to dilute wastes.
c. Rotating Biodisks	Circular disks are mounted on a central shaft and rotated while completely submerged in an enclosed housing. Biofilm grows over the disks and stabilizes the organic wastes.
d. Denitrification	The attached growth in an anaerobic environment, and in the presence of a carbon source, reduces nitrite and nitrate into gaseous nitrogen.
3. Combined Suspended and Attached Growth	The attached and suspended microbiological growth in an anaerobic environment consumes the organic matter.
C. AEROBIC -ANAEROBIC STABILIZATION PONDS	Stabilization ponds are earthen basins with impervious liner. The basins may be aerobic, facultative, or anaerobic depending upon the depth and strength of wastes. Source of oxygen is natural aeration.
D. LAND TREATMENT	The waste is applied over land to utilize plants, soil matrix and natural phenomena to treat waste by a combination of physical, chemical and biological means. The methods of land application are slow-rate irrigation, rapid infiltration-percolation, and over-land flow.

11.4. Characteristics of Sinop (Meşedağı) Landfill Leachate

11.4.1. Influent Concentrations

The characteristics of Sinop landfill leachate are determined by considering the average values (especially the values of Turkey) given in Table 11.1 are as follows :

COD	≅ 35,000 mg/l	COD / BOD_5 = 0.6 – 0.8
BOD_5	≅ 25,000 mg/l	
TKN	≅ 2,300 mg/l	TKN / NH_3-N = 1.15
NH_3-N	≅ 2,000 mg/l	
TP	≅ 5 mg/l	
pH	≅ 6 – 8 mg/l	
Alkalinity	≅ 11,000 mg as $CaCO_3$ / l	
Fe	≅ 100 mg/l	

The assumption of the leachate flowrate is very important for the design of leachate treatment plant.

11.4.2. Leachate Flowrate

As it was mentioned in Section 8, HELP model can generate more realistic results on landfill leachate generation quantities. The leachate generation rate is higher during the active life of the landfill and reduced gradually after the construction of the final cover. The procedure for evaluating and selecting design flowrates usually involves the development of average flowrates based on population projections. According to the Figure 8.8a. and 8.8b., which gives the total leachate generation during the project period, it is seen that average leachate generation is about 35,000 m^3/year. The maximum flowrate will be 58,648 m^3/year only in 2014 and the minimum will be 12,334 between year 2028 and 2031.

11.5. Discharge Standards for Leachate in Turkey

Effluent from the designed leachate treatment plant, which will be discharged to Black Sea via creek, will achieve the following standards according to the Water Pollution and Control Regulation, 1988, Table 6.20 (Solid Waste Recovery and Disposal Facilities). These values are given in Table 11.3.

Table 11.3. Effluent standards for Sinop (Meşedağı) sanitary landfill leachate (Water Pollution and Control Regulation, 1988)

Parameters	Unit	2 Hours Composit Sample	24 Hours Composite Sample
BOD_5	mg / l	100	50
COD	mg / l	160	100
SS	mg / l	200	100
Oil and Grease	mg / l	20	10
Total Phosphorus	mg / l	2	1
Total Chromium	mg / l	2	1
Cr +6	mg / l	0.5	0.5
Pb	mg / l	2	1
Total Cyanide (CN)	mg / l	1	0.5
Cd	mg / l	0.1	
Fe	mg / l	10	
F-	mg / l	15	
Cu	mg / l	3	
Zn	mg / l	5	
PH		6 – 9	6 – 9

11.6. Description of the Leachate Treatment Plant

For treatment of landfill leachate, the suggested general approach is to utilize physical treatment processes in conjunction with (a) biological treatment and (b) chemical treatment. Many studies previously summarized clearly that the use of physical-chemical treatment processes on leachate from young fills does not produce the degree of organic removal that can be accomplished with biological treatment processes. However, good results with physical-chemical treatment are observed with stabilized leachate collected from old fills. Similarly, good results are obtainable with leachate which has been stabilized biologically with both anaerobic and aerobic processes (Quasim et.al., 1994). The leachate treatment system must meet the level of effluent quality established in the regulation. In the selection of leachate treatment plant in Sinop (Meşedağı), the main criteria was the effluent standards stated in the Water Pollution and Control Regulation, 1988, for the disposal into receiving waters. To ensure these criteria, the proposed treatment plant in involves aerobic and anaerobic processes with high removal efficiencies. The process is; equalization tank, ammonia stripping unit in combination with pH adjustment, anaerobic upflow hybrid bed reactor, pre-ozonation, sequenching batch reactor (SBR), post-ozonation, sand filter and granular activated carbon (GAC) filter units. The flow diagram of the treatment plant is given in Figure 11.1.

11.6.1. Equalization Tank

Equalization tank is used for the flow equalization. Flow equalization simply is the regulation of flowrate variations so that a constant or nearly constant flowrate is achieved (Tchobanoglous et al., 1991). Mixing is usually provided to ensure adequate equalization and prevent settleable solid from depositing in the basin. The most common method of mixing is to use submerged mixers or surface aerators.

The influent, effluent characteristics and the dimensions of selected equalization basin are as follows :

Influent Characteristics :

COD	= 35,000 mg / l
BOD_5	= 25,000 mg / l
TKN	= 2,300 mg / l
$NH_3 - N$	= 2,000 mg / l
TP	= 5 mg/ l
pH	= 6
Alkalinity	= 11,000 g as $CaCO_3$ / l
Fe	= 100 mg / l

Effluent Characteristics :

Negligible COD and ammonia removal

COD	= 35.0000 mg / l	
BOD_5	= 25,000 mg / l	
TKN	= 2,300 mg / l	
$NH_3 - N$	= 2,000 mg / l	
TP	= 5 mg/ l	
pH	= 6	
Alkalinity	= 11,000 g as $CaCO_3$ / l	Fe = 100 mg / l

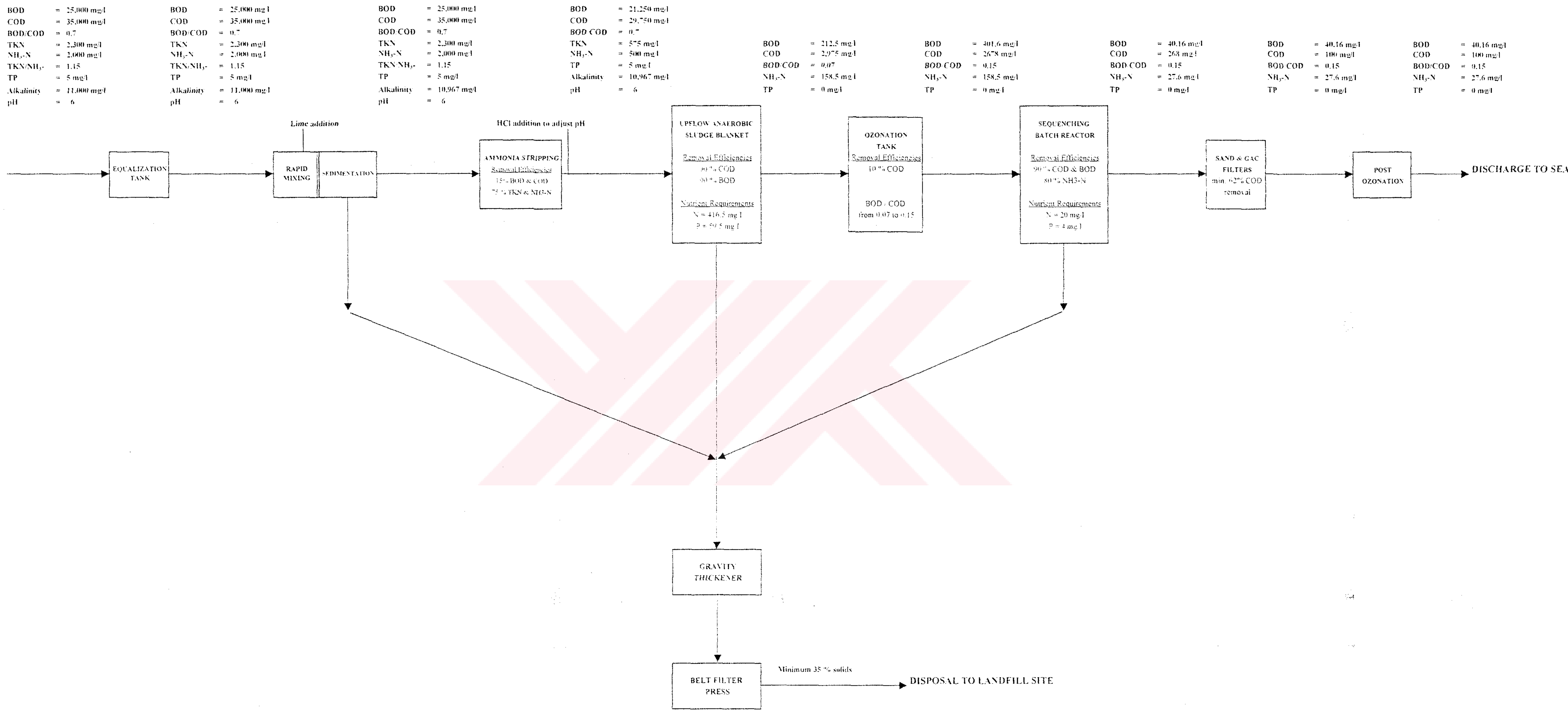


Figure 11.1. Flow diagram of the Sinop (Meşedağı) sanitary landfill leachate treatment plant

11.6.2. Ammonia Stripping Tank

Ammonia stripping operations consist of converting ammonium to the gaseous phase and then dispersing the liquid in air, thus allowing transfer of the ammonia nitrogen in wastewater to the air. The gaseous phase NH_3 and the aqeous phase NH_4^+ exist together in the equilibrium as indicated in Eq. 10.1. The relative abundance of the phases depends upon pH. pH must be in excess of 11 for complete conversion to NH_3. Since pH of 11 is well above the pH of young landfill leachate, pH adjustment is necessary prior to ammonia stripping. For economic reasons, lime is the most common means of raising the pH.

Ammonia Toxicity :

Ammonia may be present either in the form of the ammonium ion (NH_4) or as dissolved ammonia gas (NH_3). These two forms are in equilibrium with each other and relative concentrations of each depends upon the pH or hydrogen ion concentration as indicated in the following equilibrium reaction:

$$NH_4^+ + OH^- \leftrightarrow NH_3 + H_2O \quad (11.1)$$

When the hydrogen ion concentration is sufficiently high (pH of 7.2 or lower), the equilibrium is shifted to the left and increasing ammonium ion concentration may cause inhibition. At higher pH levels the equilibrium shift is to the right and the ammonia gas concentration increases. If ammonia concentration is between 1,500 and 3,000 mg/l and pH is greater than 7.4 to 7.6, the ammonia gas concentration can become inhibitory. This condition is characterised by an increase in volatile acid concentration, which tends to decrease the pH, temporarily relieving the inhibitory condition.

The effect of ammonia nitrogen concentration on anaerobic treatment is summarised in Table 11.3. As it is seen from the table, ammonia concentration greater than 1,500 mg N/l can cause inhibition of anaerobic treatment. Since young landfill leachate in Turkey contains high ammonia concentrations, ammonia concentration should be decreased to non-inhibitory levels before anaerobic treatment system. Thus, it is better to place ammonia stripping unit prior to anaerobic treatment unit in the leachate treatment plant of Sinop (Meşedağı) sanitary landfill.

Table 11.4. Effect of ammonia nitrogen on anaerobic treatment (Tchobanoglous et al., 1991)

Ammonia Nitrogen Concentration (mg/l)	Effect on Anaerobic Treatment
50 – 200	Beneficial
200 - 1,000	No adverse affect
1,500 – 3,000	Inhibitory at higher pH values
above 3,000	Toxic

Selected ammonia stripping unit consists of rapid mixing basin in which pH adjustment will be made with the addition of lime, sedimentation basin and ammonia stripping basin. The details of these basins are as follows :

a) Rapid Mixing Basin :

In this unit, lime will be added to the leachate for the adjustment of pH to 11.5.

Influent Characteristics :

pH = 6
Alkalinity = 11,000 mg as $CaCO_3$ / l

Lime Requirement Calculation (Tchobanoglous et al., 1991) :

pH before lime addition : 6
pOH before lime addition : 8 $[OH^-] = 10^{-8}$ mol / l

pH after lime addition : 11.5
pOH after lime addition : 2.5 $[OH^-] = 10^{-2.5}$ mol / l

OH^- needed : $10^{-2.5} - 10^{-8} = 0.003$ mol / l

$= 0.054$ g / l

Molecular weight of $Ca(OH)_2$ = 74 g. → OH^- = 2 x 17 = 34 g

Lime requirement to increase pH to 11.5 = (0.054 x 34) / 74 = 0.025 g / l.

Purity of lime = 90 %

Sludge produced and Alkalinity consumed :

$$Ca(OH)_2 + Ca(HCO_3)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O \quad (11.2)$$

74 g	100 as $CaCO_3$	200 g
0.024 g/l	?	?

Alkalinity consumed = (0.025 x 100 / 74) = 0.033 g as $CaCO_3$ / l = 33 mg / l

Effluent Characteristics :

pH = 11.5

Alkalinity = (11,000 – 33) = 10.967 mg as $CaCO_3$ / l

b) Sedimentation Basin :

Circular type sedimentation basin with scrapers will be used for the sedimentation of sludge containing lime.

c) Ammonia Stripping Tank :

Influent Characteristics :

COD = 35,000 mg / l

BOD_5 = 25,000 mg / l

TKN = 2,300 mg / l

$NH_3 - N$ = 2,000 mg / l

TP = 5 mg/ l

pH	= 11.5
Alkalinity	= 10,967 mg as $CaCO_3$ / l

COD removal efficiency	: 15 %	COD removed	: 5,250 mg/l
BOD removal efficiency	: 15 %	BOD removed	: 3,750 mg/l
NH_3-N removal efficiency	: 75%	NH_3-N removed	: 1,500 mg/l
TKN removal efficiency	: 75 %	TKN removed	: 1,725 mg/l

Effluent Characteristics :

COD	= 29,750 mg / l
BOD_5	= 21,250 mg / l
TKN	= 575 mg / l
NH_3 – N	= 500 mg / l
TP	= 5 mg/ l
pH	= 7 – 8 (pH will be re-adjusted to 7-8 by HCl addition at the outlet)
Alkalinity	= 10,967 mg as $CaCO_3$ / l

11.6.3. Upflow Anaerobic Sludge Blanket

In the upflow anaerobic sludge blanket (UASB) process, the waste to be treated is introduced at the bottom of the reactor. The wastewater flows upward through a sludge blanket composed of biologically formed granules and particles. Treatment occurs as the wastewater comes in contact with the granules. The gases produced under anaerobic conditions cause internal circulation, which helps in the formation and maintenance of the biological granules. The free gas and the particles with the attached gas rise to the top of the reactor. The particles that rise to the surface strike the bottom of the degassing baffles, which causes the attached gas baffles to be released. The degassed granules typically drop back to the surface of the sludge blanket. The free gas and the gas released from the granules is captured in the gas collection domes located at the top of the reactor. Liquid containing some residual solids and biological granules passes into a settling chamber where the residual solids are separated from the liquid. The separated solids fall back through the baffle system to the top of the sludge blanket. To keep the sludge blanket in suspension, upflow velocities in the range of 0.6 to 0.9 m/h have been used.

Influent Characteristics :

COD	= 29,750 mg / l
BOD_5	= 21,250 mg / l
TKN	= 575 mg / l

(After anaerobic treatment, effluent TKN can be taken equal to the effluent $NH_3 - N$ since it is converted to $NH_3 - N$ through anaerobic treatment).

$NH_3 - N$	= 500 mg / l
TP	= 5 mg/ l
pH	= 7 - 8
Alkalinity	= 10.967 mg as $CaCO_3$ / l

Design Values (İnanç et al., 2000) :

COD removal efficiency	: 90 %	COD removed : 26.775 mg/l
BOD removal efficiency	: 99 %	BOD removed : 21.038 mg/l

Nutrients Requirement :

Chosen C/N/P ratio	: 500 / 7 / 1
Nitrogen requirement	: 416.5 mg / l
Available nitrogen	: 575 mg / l
Remaining nitrogen	: 158.5 mg / l
Phosphorus requirement	: 59.5 mg / l
Available phosphorus	: 5 mg / l

Phosphorus to be added before anaerobic treatment : 54.5 mg / l

Effluent Characteristics :

COD	= 2.975 mg / l	
BOD_5	= 212.5 mg / l	(BOD_5 / COD = 0.07)
$NH_3 - N$	= 158.5 mg / l	
TP	= -	

11.6.4. Ozonation Unit

The main aim using an ozonation unit is that the removal of ozonated leachate is higher. The experiments show that after preozonation about 40 % of the remaining organic substances are biodegradable (Fettig et al., 1996).

Ozone is an extremely reactive oxidant, and it is generally believed that bacterial kill through ozonation occurs directly because of cell wall disintegration (cell lysis). Ozone is also very effective virucide and is generally believed to be more effective than chlorine. Ozonation does not produce dissolved solids and is not effected by the ammonium ion or pH influent to the process. For these reasons, ozonation is considered as a viable alternative to either chlorination or hypochlorination, especially where dechlorination may be required (Tchobanoglous et al., 1991).

In this project, to remove color and odor, and increase biological degradation, an intermittent ozonation unit will be installed before the aerobic treatment unit.

Influent Characteristics :

COD	= 2,975 mg / l	
BOD_5	= 212.5 mg / l	(BOD_5 / COD = 0.07)
$NH_3 - N$	= 158.5 mg / l	
TP	= -	

Design Values (Geenens et al., 1999 and Steensen, 1997) :

COD removal efficiency	: 10 %	COD removed	: 297.5 mg/l
Remaining COD	: 2,678 mg/l		

Increase in BOD_5 / COD ratio : from 0.07 to 0.15

Increased BOD : (0.15 x 2 678 mg/l) = 401.7 mg / l

Effluent Characteristics :

COD	= 2,678 mg / l	
BOD_5	= 401.6 mg / l	(BOD_5 / COD = 0.15)
$NH_3 - N$	= 158.5 mg / l	
TP	= -	

11.6.5. Sequencing Batch Reactor (SBR)

A sequencing batch reactor is a fill and draw activated sludge treatment system. The unit processes involved in the SBR and conventional activated-sludge systems are identical. Aeration and sedimentation/clarification are carried out in both systems. However, there is one important difference. In conventional plants, the processes are carried out simultaneously in separate tanks, whereas in SBR opearation the processes (carbon removal, nitrification and denitrification) are carried out sequentially in the same tank (Tchobanoglous et al., 1991).

Influent Characteristics :

COD	= 2,678 mg / l
BOD_5	= 401.6 mg / l
$NH_3 - N$	= 158.5 mg / l
TP	= -

Nutrients Requirement :

Chosen C/N/P ratio	: 100 / 5 / 1
Nitrogen requirement	: 20 mg / l
Available nitrogen	: 158.5 mg / l
Remaining nitrogen	: 138.5 mg / l
Phosphorus requirement	: 4 mg / l
Available phosphorus	: 0 mg / l
Phosphorus to be added before aerobic treatment	: 4 mg /l

Design Values (Tchobanoglous et al., 1991) :

COD removal efficiency	: 90 %	COD removed	: 2,410.2 mg/l
BOD removal efficiency	: 90 %	BOD removed	: 361.44 mg/l
N removal efficiency	: 10 %	N removed	: 110.7 mg / l

Effluent Characteristics :

COD	= 268 mg / l
BOD_5	= 40.16 mg / l
$NH_3 - N$	= 27 mg / l
TP	= -

11.6.6. Sand and Granular Activated Carbon (GAC) Filters

Activated carbon is prepared by first making a char from materials such as almond, and wallnut halls, other woods, and coal. A fixed-bed column is often used as a means of contacting wastewater with GAC. The water is applied to the bottom of the column and withdrawn at the bottom. The carbon is held in place with an underdrain system at the bottom of the column. Provision for backwashing and surface washing is usually necessary to limit the headloss buildup due to the removal of particulate matter within the carbon column. Expanded-bed and moving-bed carbon contactors have also been developed to overcome the problems associated with headloss buildup. In the expanded-bed system, the influent is introduced at the bottom of the column and is allowed to expand, much as a filter bed expands during backwash. In the moving-bed system, spent carbon is displaced continuously with fresh carbon. In such a system, headloss does not build up with time after the operating point has been reached (Tchobanoglous et al., 1991).

To capture the biological flocs escaping from SBR unit, it is recommended to place a sand filter following to the SBR unit. Moreover, since the COD of SBR effluent (268 mg/l) is above th effluent discharge COD limit given in Table 7.2 (100 mg/l), an activated carbon filter should be placed after the sand filter. 62 % COD removal to be achieved in activated carbon unit will be enough to reach effluent COD limit of 100 mg/l.

11.6.7. Post Ozonation Unit

A post ozonation unit will be placed after the slow sand and GAC filters for disinfection of effluent.

11.6.8. Sludge Treatment

According to the Solid Waste Control Regulation (14.03.1991, No: 20814), Clause 28, sludge from any treatment plant can be disposed to sanitary landfill site only if its water content is maximum 65 % (solids content of 35 %). For this reason, sludge from sedimentation basin of rapid mixing unit, anaerobic upflow hybrid bed reactor and SBR will be treated through gravity thickener and belt filter presses to achieve the desired solids content of 35 %.

11.6.8.1. Gravity Thickener : Gravity thickening is accomplished in a tank similar in design to a conventional sedimentation tank. Normally, a circular tank is used. Dilute sludge is fed to a center-feed well. The feed sludge is allowed to settle and compact, and the thickened sludge is withdrawn from the bottom of the tank. Conventional sludge-collecting mechanisms with deep trusses or vertical pickets are used to stir the sludge gently, thereby opening up channels for water to escape and promoting densification. The supernatant flow that results is returned to the headworks of the treatment plant. The thickened sludge that collects on the bottom of the tank is pumped to the digesters or dewatering equipments as required; thus, storage space must be provided for the sludge (Tchobanoglous et al., 1991).

11.6.8.2. Belt Filter Press : Belt filter presses are continuous-feed sludge-dewatering devices that involve the application of chemical conditioning, gravity drainage, and mechanically applied pressure to dewater sludge. These three basic stages of belt press dewatering is shown schematically in Figure 11.3. The final dewatered sludge cake is removed form the belts by scraper blades (Tchobanoglous et al., 1991).

12. CLOSURE OF LANDFILL AND LONGTERM MONITORING

12.1 Closure of Landfills

Landfill design and construction is a continuous activity that is completed only when all of the available or permitted capacity of the site has been filled with solid waste. Once that happens, the landfill must be closed, the final action of a facility that is to receive no more solid wastes. To ensure the functioning of environmental controls during closure and for a period of time after closure, a closure plan must be developed early in the life of a landfill, often at the design or site development phase (Tchobanoglous et al., 1993).

The elements of a closure plan are identified in Table 12.1.

Table 12.1. Typical elements of a landfill closure plan (Tchobanoglous et al., 1993)

Element	Typical activity
Postclosure land use	Designation and adoption
Final cover design	Select the infiltration barrier, final surface slope and vegetation
Surface water and drainage control systems	Calculate stormwater quantities for runoff and select perimeter channel location and sizes to collect runoff and to prevent runon
Control of landfill gases	Select locations and frequency of gas monitoring and set the operations schedule for gas extraction wells and flare, if required
Control and treatment of leachate	Set the operation schedule for leachate removal and treatment, if required
Environmental monitoring systems	Select sampling locations and frequency of monitoring as well as constituents to be measured

12.2. Environmental Monitoring System

The final part of a closure plan involves the environmental monitoring facilities. Environmental monitoring is necessary to ensure that the integrity of the landfill is maintained with respect to the uncontrolled release of any contaminants to the environment. In most instances, the selection of facilities and procedures to be included in a closure plan will be a function of the environmental control facilities used during landfill operations before closure (Tchobanoglous et al., 1993). These facilities and their functions are given in Table 12.1.

Table 12.2. Environmental Monitoring Facilities that are Installed During Landfill Construction and Operations and Used after Landfill Closure (Tchobanoglous et al., 1993)

Monitoring Facility	Function During Operation	Function After Closure
Groundwater Monitoring Wells		
Upgradient	Water sampling at location to get background water quality.	Same functions as during operation.
Downgradient	Water sampling at location to detect movement of leachate contaminants;if contaminants are present, stop operations and correct problem with liner; wells function as a control variable for operations.	Water sampling at location to detect any leachate plume created by a leaking liner; a data reference location for defining the direction and rate of movement for a contaminant plume.
Vadose Zone Lysimeters	Sampling locations to detect liquids in soils above groundwater; if liquids are present, stop operations and determine the cause; correct problems before restarting operations.	Sampling locations to detect liquids in soils above groundwater; if liquids are present, complete additional investigations as to cause; correct any problems as required by regulatory agency.
Gas Vents	Sampling location for combustible gases.	Sampling location for combustible gases; gas extraction wells for control and removal of methane gas after closure.
Leachate Treatment Facilities	Leachate quantity measurement and quality sampling location.	Same functions as during operation.
Stormwater Holding Basins	Retain stormwater for regulated release of basins; measure quantity and sample for quality.	Same functions as during operation.

Monitoring facilities that can be used to track the movement of any landfill emissions to the water, air and soil environments should be chosen (Tchobanoglous et al., 1993).

Water

Monitoring of water quality and movement is done to identify leachate leakage from landfill. Monitoring facilities will be placed in soils under the landfill liner and in the uppermost groundwater aquifer. In dry climates, where moisture does not penetrate to soils beneath the landfill, the monitoring facilities must be capable of functioning in the vadose zone. The vadose zone is defined as that zone from the ground surface to where the permanent groundwater is found. The groundwater aquifer is monitored by wells (Tchobanoglous et al., 1993).

Air

A landfill closure plan will show the manner in which methane and other gases are to be controlled and discharged to the atmosphere. Gas monitoring is also used to asses the degree of biological activity in the landfill. Typical gas monitoring equipment used at closed landfills includes explosive gas meters, hydrogen sulfide meters, and sample collection equipment and containers for samples to be analyzed off-site (Tchobanoglous et al., 1993).

Soil

In most landfill closure plans, cover soil is one of the most important features. It must be placed under strict construction supervision, and then maintained to prevent loss of soils. Environmental monitoring of soils includes measuring land surface settlement, soil slippage, and land surface erosion. Inspection of closed landfills requires training and good judgement in making visual observations and in the use of survey monuments to monitor cover layer movement (Tchobanoglous et al., 1993).

13. SUMMARY AND CONCLUSIONS

The purpose of this study was to present proper design elements of a sanitary landfill through a case study, Sinop (Meşedağı) sanitary landfill project. The study involves the application of a variety of scientific, economic and engineering principles. The main criteria in design studies were the Turkish Environmental Laws.

A summary of the key findings of this study are presented below :

1. First of all, a landfill site has to meet several locational and geotechnical design criteria and be acceptable to the public. Due to locational criteria, a landfill cannot be sited within a certain distance of the following: lakes, ponds, rivers, wetlands, flood plain, highway, critical habitat areas, water supply well, and airports. In addition, landfill siting is not allowed in areas in which a potential for contamination of groundwater or surface water bodies exist. The purpose of the geotechnical investigation is primarily to obtain data to study the different soil stratum present at the site and to prepare a groundwater map of the site. Sinop (Meşedağı) sanitary landfill site meet all these locational and geotechnical criteria. The nearest residential area is Eldevüz District with a distance of 1 250 m and the distance to the airport is more than 3 km. The only protection zone is the area around the Sarıkum Lake which is so far from the project area. According to the geotechnical evaluations at the site, the soil layers in 2 m height section from ground-surface to the bottom consist of :

- 30 cm vegetable soil
- Clay with silt (yellow colored, high solid consistency)
- Hard Clay layer (brown color)

The permeability tests showed that the permeability of the yellow silty clay layer was higher than 1×10^{-8} and the brown hard clay layer is smaller than 1×10^{-8}. The results of the tests also showed that by the compaction of these layers after excavation the permeability will be smaller than 1×10^{-8} as mentioned in Solid Waste Control Regulation.

One of the major issues of selecting and designing landfill site is data collection. In this study, most of the data, basic for the design studies were collected from Sinop Governorship and State Institute for Statistics. The data collection mainly involves the evaluation of topographic maps. soil maps, land use plans, transportation plans, waste type and volume, and population data.

2. After these preliminary studies, the planning and design studies have been started. The first step of the project include the estimation of population projections. The four methods selected for population projections were Geometric, Arithmetic, Linear Regression and Bank of Provinces methods. The population values calculated by Bank of Provinces method is chosen as it gives the average values compared to other 3 methods. These values are accepted as basis in calculation of solid waste quantities.

3. The quantity of the solid wastes produced in the project area is one of the major components used in the design of a sanitary landfill. The wastes that will be deposited in Sinop (Meşedağı) sanitary landfill include MSW from residences. MSW from military services, MSW from industrial facilities, and dewatered sludge from domestic wastewater treatment plant. Additionally, the estimation of recoverable MSW and hospital waste quantities are calculated, though the project does not include a recovery plant project and disposal of hospital wastes. Annual MSW generation from residences was calculated by multiplying the project population with the unit solid waste generation. Unit solid waste generation in year 2000 was estimated as 660 g/cap/day, and after 2000, it was assumed that there will be 1% annual increase in unit solid waste generation. The data about MSW generation from military services and industrial services were obtained from different studies, and the generation in the future was calculated. The estimation about the potential treatment sludge generation is performed by multiplying the unit sludge production with the project population. The unit sludge production rate is assumed as 11.28 g/cap/day. As a result, the total amount of waste that will be deposited in Sinop (Meşedağı) sanitary landill is estimated as 762,620 tonnes.

4. After the estimation of solid waste quantity, types and composition of the solid wastes are observed. These information are the basic data in estimating the amount of landfill gas generation. The types of the solid waste that will be deposited in Sinop

(Meşedağı) sanitary landfill include food wastes, papers, plastics, textiles, woods, metals, dirt, ash and treatment sludge. The studies about the residential MSW composition in Sinop showed that 26.5% of the MSW is inorganic when 79.82% is organic. These values are compared with the ones in İstanbul and the U.S., and it is observed the total organic content of MSW in the U.S. is 79.5%, when it is 73.5% in İstanbul. The differences are largely due to improved food processing techniques and the increased use of kitchen food waste grinders, the increased use of plastics for food packaging and other packaging, and the fact that the burning of yard wastes is no longer available in most communities. The most significant differences between the wastes of Sinop, İstanbul and the U.S. is that food wastes content in Sinop is 54.19% when it is 48% in İstanbul and 9% in the U.S. This is due to the use of kitchen food waste grinders in the U.S. Also, in the U.S. the content of paper and yard waste are very high. However, the total organic content of the waste in Sinop is similar to the organic content in the wastes of U.S.

5. The total area of the landfill site is about 16 hectars and the facility will serve for 30 years. The principal method used for the landfilling in Sinop (Meşadağı) is the excavated cell/trench method. The excavated cell/trench method of landfilling is ideally suited to areas where an adequate depth of cover material is available at the site and where the water table is not near to the surface. Solid wastes will be placed in cells and the soil excavated from the site will be used for daily and final cover. The total cell height of the daily waste deposited in the landfill will be 2m. First, the wastes will be deposited with layers of 0.5 m height and then pressed. Secondly, the sub-covers of 0.20 m height soil will be layered. Finally, daily cover will be layered. Due to the topographical properties and the period of service, three lots have been planned. Lot-1 will serve between years 2000-2015, when Lot-2 serves between 2015-2028 and Lot-3 between 2028-2030.

The other units within the landfill site are leachate treatment plant, administration building, separation unit, garage and workshop, guard house, steelyard, transformer building, generator building, wheel washing unit, autopark, daily cover soil storage area and the access roads.

6. After the establishment of the lots, stability analysis are performed. Both berms around a landfill and the waste slopes should be checked for stability in every landfill

project. The "method of slice" analysis are performed for every lot in Sinop (Meşedağı) landfill and the results showed that sufficient security will be provided.

7. The design of liner systems are one of the major issue in landfill projects. Landfill liners minimize the infiltration of leachate into the subsurface soils below the landfill thus eliminating the potential for groundwater contamination. In the design of sub-base liner system and final cap of Sinop (Meşedağı) landfill, Turkish Solid Waste Control Regulation is the main criteria. Also, low permeability, robustness, durability, and resistivity to chemical attract, puncture and rupture are taken into consideration. Finally, sub-base liner system from bottom to the top include natural soil basement, compacted clay layer, geomembrane liner, protective sand layer, leachate drainage layer and drainage protective gravel layer. The final cap includes stabilizing barrier soil layer, gas drainage layer, barrier clay layer, drainage layer and vegetative agricultural soil layer.

8. One of the important environmental concern in sanitary landfills is the production of leachate. Many factors like annual precipitation, runoff, infiltration, evaporation, transpiration, freezing, waste composition, waste density, initial moisture content and depth of the landfill affect the amount of leachate generated. The two mathematical models selected to calculate the potential leachate quantity from Sinop (Meşedağı) Sanitary Landfill were Hydraulic Evaluation of Landfill Performance (HELP), and Water Balance Model based on potential evapotranspiration. HELP, developed by EPA, is a mass balance model capable of estimating leachate quantities through the different components of a landfill for variable climatic conditions. On the other hand, the Water Balance Model based on potential evapotranspiration is an MS Excel implementation of the Thornthwaite and Benfratello formula.

The HELP model uses weather (climatic), soil and design data to generate daily estimates of water movement across, into, through and out of landfills. In order to accomplish this objective and to compute a water balance, daily precipitation is partitioned into surface storage, snowmelt, interception, runoff, infiltration, surface evaporation, evapotranspiration from soil, subsurface moisture storage, liner leakage (percolation), and subsurface lateral drainage to collection, removal and recirculation systems. The weather data required in the HELP model are classified into four groups: (1) evapotranspiration, (2) precipitation, (3) temperature and, (4) solar radiation data. Additionally, the model requires values for the total porosity, field capacity, wilting point, and saturated hydraulic conductivity of each layer that is not a liner.

To provide an independent check on the HELP model results, the *Water Balance Model* based on potential evapotranspiration was also used to estimate the potential leachate. The water balance model was used to estimate the potential leachate generation for the Sinop (Meşedağı) sanitary landfill since it is the most widely used approach in Turkey for the estimation of leachate. The water balance model is generally based on the Thornthwaite formula to calculate potential evapotranspiration and the Benfratello formula to calculate the monthly percolation quantity in landfills. However, it should be noted that this model does not consider moisture to be held by the landfill layers. Thus, the percolating liquid amount is accepted as the total leachate quantity generated from the landfill. Among several empirical/theoretical equations available for estimating the potential evapotranspiration and the leachate generation rate in the landfills. Thornthwaite-Benfratello equations were chosen since they use an exponential relationship between mean monthly temperature and mean monthly heat index, which is considered more appropriate. Moreover, Thornthwaite-Benfratello method was especially developed for determining the rate of effective evapotranspiration in European climates and is widely used to predict evapotranspiration from landfill cover.

Taking into account all the advantages and limitations of the two models, the HELP model should be preferred for landfill water budget analysis, despite the extra effort needed to simulate the results. Also, HELP model can generate more realistic results on landfill leachate generation quantities.

As it is seen from the results of the HELP model for leachate generation, the preclosure and postclosure leachate generation rates vary significantly. The leachate generation rate is higher during the active life of the landfill and is reduced gradually after the construction of the final cover. However, the results of Water Balance model gives only average leachate generation. Also, annual leachate quantities calculated by Water Balance Model is about 18% of the annual leachate quantities calculated by HELP model. Finally, HELP model should be preferred for landfill water balance analysis and for the design of the leachate treatment plant. The total annual leachate generation estimated by HELP model vary between 12,334 m^3/yr and 58,648 m^3/yr.

9. The leachate collection system is planned according to the Bank of Provinces' technical specification. It states that all the rainwater and the leachate generated will be collected with the leachate collection system. This means that the pipes will be designed larger to be on the secure side. Also, it states that the leachate collection pipes placed into the trenches and the minimum pipe diameter will be 150 mm. The slope of the pipes will be %1 and over the pipes, a layer of 30 cm height 15/40 mm granular material will be covered. The distance between the pipes will not exceed 100 m. Finally, Rational Method is used in the design of leachate collection pipes and the diameter of the circular pipes varies between 20 cm and 50 cm.

10. The management of all surface waters is very important in controlling the movement of leachate. Reduction of the amount of surface water that enters the landfill is of fundamental importance in the design of a sanitary landfill, because surface water is the major contributor to the total volume of leachate. Surface water drainage system includes two structures: surface water ditch and culvert.

In Sinop (Meşedağı) sanitary landfill, the trapezoid shaped stormwater ditch is designed by using a trial-and-error method together with Rational method. As a result, a trapezoid shaped with W = 0.5 m and H = 0.35 m ditches are designed.

In design and calculation of the culvert dimensions, Manning's formula is used and finally the concrete pipes with diameter vary from 150 mm to 500 mm are designed.

11. The generation of landfill gas is the result of the decomposition of the organic matter present in substantial percentages in municipal solid waste, under anaerobic conditions which occur usually soon after filling the refuse under sanitary landfilling methods. The gas generation in Sinop (Meşedağı) sanitary lanfill is estimated by the application of LandGEM model and calculation by its chemical formula.

The Landfill Gas Emissions Model can be used with two different sets of default values; CAA defaults and AP-42 defaults. The CAA default values in the model provide emission estimates that would reflect the expected maximum emissions and generally would be used only for determining the applicability of the regulations to a landfill. To estimate actual emissions in the absence of site-specific data, a second set of default values (the *AP-42* defaults) is provided in the model. The *AP-42* default values in the model are based on emission factors from the U.S. Environmental Protection Agency's *Compilation of Air Pollutant Emission Factors, AP-42*. The *AP-42* default values provide emission estimates that should reflect typical landfill emissions and are the values suggested for use in developing estimates for state inventories.

The gas generation calculation by using the chemical formula of the gas includes the calculations of two classifications: (1) those materials that will decompose rapidly (three months to five years) and (2) those materials that will decompose slowly (up to 50 years or more).

The results show that the total gas generation calculated by LandGEM CAA defaults is 229.598.716 m^3 when it is 134.357.958 m^3 with AP42 defaults. The calculation according to the chemical formula gave 158.624.992 m^3 gas generation. The results showed that the calculation by chemical formula gives the average value.

12. Selection and design of a leachate treatment process is not simple. Important factors that govern the selection and design of treatment facilities include leachate characteristics, effluent discharge alternatives, technological alternatives, costs, and permit requirements. In Sinop (Meşedağı) the main criteria was the effluent standards stated in the Water Pollution and Control Regulation, 1988. To ensure these criteria, the proposed treatment plant in Sinop (Meşadağı) involves expensive processes with high removal efficiencies. The processes are equalization tank, ammonia stripping unit in combination with pH adjustment, anaerobic upflow hybrid bed reactor, pre-ozonation, sequenching batch reactor (SBR), post-ozonation, sand filter and granular activated carbon (GAC) filter units.

13. The last issue of this study includes the closure of the landfills and the environmental monitoring. Landfill design and construction is a continuous activity that is completed only when all of the available or permitted capacity of the site has been filled with solid waste.

Once that happens, the landfill must be closed, the final action of a facility that is to receive no more solid wastes. To ensure the functioning of environmental controls during closure and for a period of time after closure, a closure plan must be developed early in the life of a landfill, often at the design or site development phase.

The final part of a closure plan involves the environmental monitoring facilities. Environmental monitoring is necessary to ensure that the integrity of the landfill is maintained with respect to the uncontrolled release of any contaminants to the environment. In most instances, the selection of facilities and procedures to be included in a closure plan will be a function of the environmental control facilities used during landfill operations before closure.

In conclusion, this study showed that planning and designing a sanitary landfill, the functional element of an integrated solid waste management, is a multidisciplinary activity involving engineering principles, economics, urban and regional planning. Before designing such a complicated system, special care should be given for the detailed site investigation. In other words, preliminary studies are strictly needed for the succesfull design and operation of the waste disposal site. The study also showed that all the planning and design steps are interrelated, and must be studied and evaluated carefully.

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